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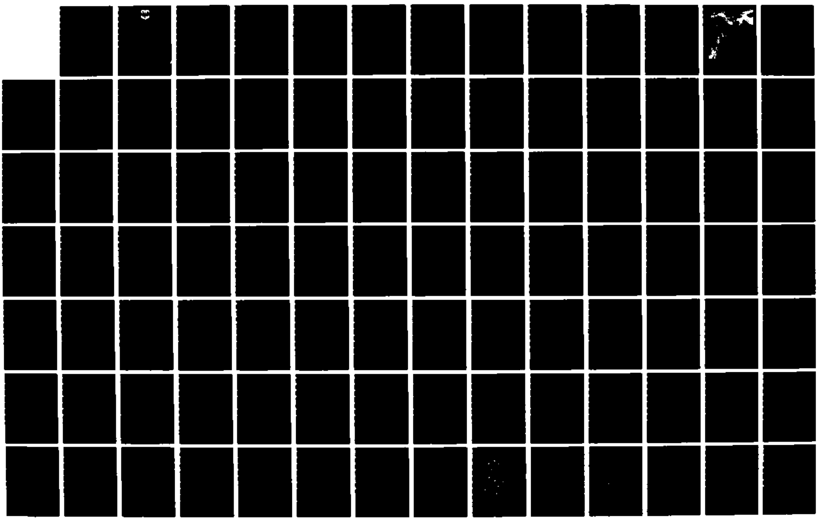

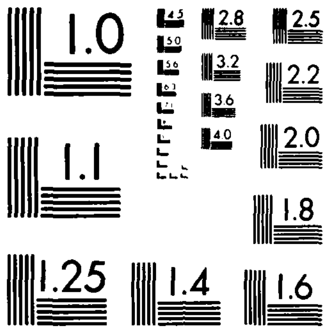

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SOUTHWEST ASIA FORECASTER'S HANDBOOK

AUGUST 1986

5WW/DNS

This handbook was designed to prepare forecasters for the meteorological conditions to expect when deployed or assigned to Southwest Asia. The handbook is divided into seasons to aid the forecasters when deploying for short periods. Technical data for this area is limited compared to other regions of the world. Suggestions for improvements to this handbook by forecasters who use it are appreciated.

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SOUTHWEST ASIA FORECASTER'S HANDBOOK

1.0. INTRODUCTION.

The Southwest Asia Forecaster's Handbook was developed to help prepare forecasters for the challenges of forecasting the weather in an area of the world where few are experienced. The handbook is an attempt to be a single reference book for most of the meteorological questions deploying forecasters will have concerning the Southwest Asia environment.

What constitutes Southwest Asia? There is much confusion since many use the terms Middle East and Southwest Asia interchangeably and the areas they use to define Southwest Asia can vary greatly. For this handbook, Southwest Asia will include the Arabian Peninsula, Arabian Sea, and the bodies of water and countries that surround them. This will include parts of northeast Africa, the countries bordering the eastern Mediterranean including Turkey, Iran and Iraq, Pakistan, and extreme northwest India. This area may be larger than that normally considered Southwest Asia, but weather does not recognize political or geographic boundaries, and we wish to include source regions for many of the important weather patterns that effect the region.

Figure 1 shows many of the major geographical and political boundaries referred to in this handbook. The names of many locations and geographical features differ widely depending on the reference source. For instance, the body of water to the east of the Arabian Peninsula is known as the Persian Gulf by some and the Arabian Gulf by others. It is extremely difficult to keep the names consistent throughout this handbook since it was written over an extended period and includes material from a multitude of sources. Hopefully, this will not be too distressing to the reader, and it probably will better prepare them for operations in this part of the world. A glossary of terms is included in an appendix to aid in reading maps of the area.

Although Southwest Asia is only a small portion of the Asian landmass, it is still a vast area. In fact, as the area is defined for this handbook, Southwest Asia is as large or larger than the continental United States. Just as there are many different weather regimes that effect the United States, the same is true of Southwest Asia. Many forecasters have a preconceived idea that forecasting for Southwest Asia is easy --- hot and dusty. This idea must be dispelled immediately. While hot and dusty may be the rule in certain areas during certain times of the year, it certainly doesn't cover every place. There are many different climates due to the vastness of the area, rugged mountains, broad intermountain plateaus, deserts of various kinds, bodies of water, and other features that influence the weather.

For many portions of Southwest Asia, there has been very limited material written about the meteorological conditions and, in fact, for many areas no meteorological data exists. This has made some sections of this handbook very sketchy. In recent years, satellite imagery has aided tremendously in providing data in data sparse areas and this should help future studies.

This handbook contains information on the meteorology, climatology, geography, topography, forecasting hints and rules, and other subjects for the area. Only general area-type climatolgical information is included to keep the handbook length manageable. References are given for more detailed, site-

specific climatology.

Since this handbook is quite voluminous, forecasters deploying to the area for short periods should only read those sections that are pertinent for the period of their visit. For this reason most of the material in the handbook has been broken into the four seasonal periods that dominate.

Suggestions for improvements to the handbook would be appreciated, especially from those who have forecasted for the area in the past or who do so in the future. Hopefully, forecasters deploying to Southwest Asia will be better prepared after having read this handbook. Forecasting for this area is a challenge, but knowledge can certainly improve your chances for success.

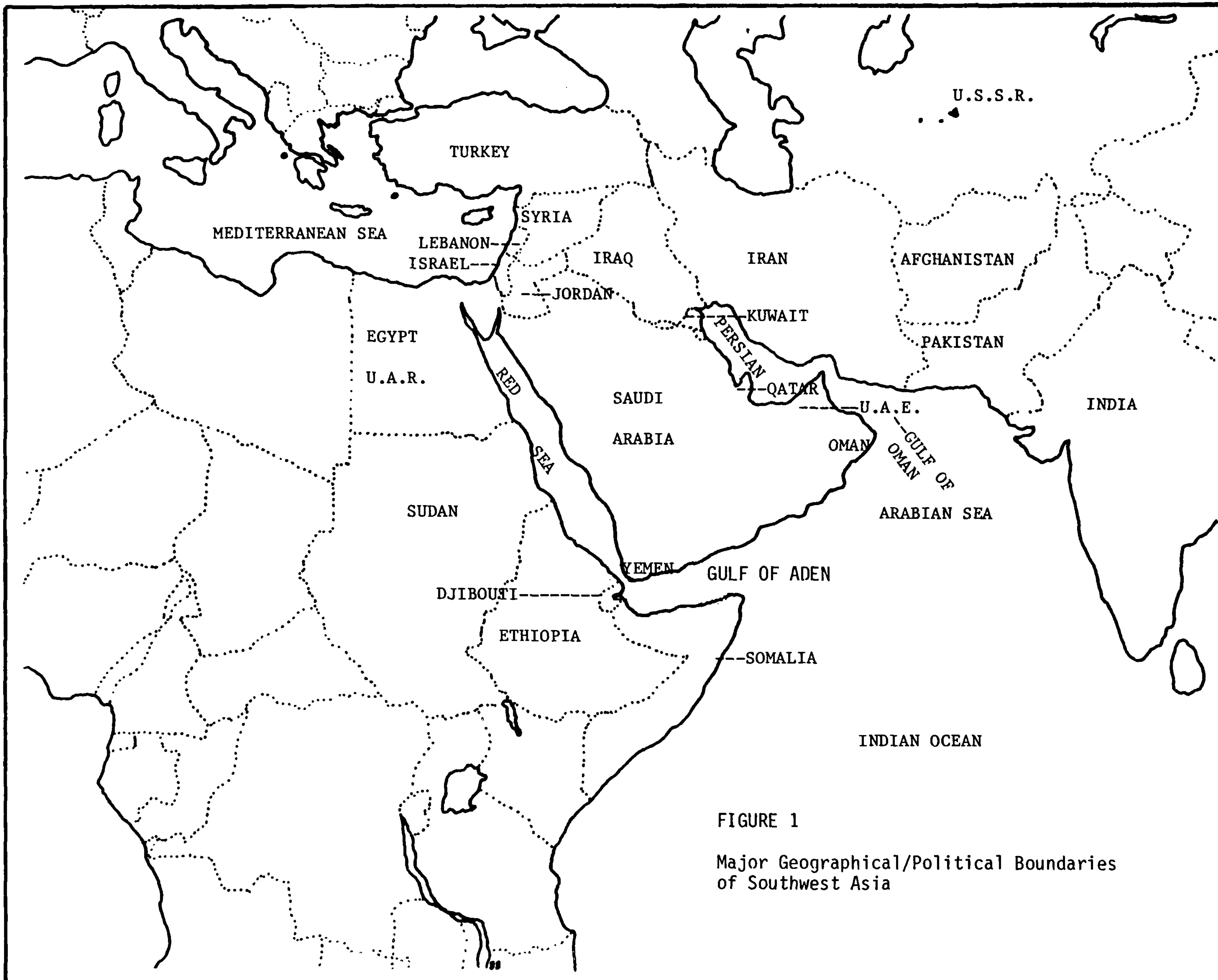

FIGURE 1

Major Geographical/Political Boundaries of Southwest Asia

1.1. TOPOGRAPHY. Preconceived ideas of the weather in Southwest Asia must be tempered by the topography of the area. Southwest Asia contains a complex of rugged mountains; broad, dry intermountain plateaus; deserts of various kinds; and a small fringe of coastal plain. Figure 2 shows a simplified picture of topographical features that characterize the region and influence the weather.

1.1.1. Highlands.

a. Elburz Mountains. The highest peak in Southwest Asia is Mt. Demavend (18,934 ft), a volcanic cone in the Elburz Mountains of northern Iran. Snow usually remains all the year only in sheltered hollows and within the crater of the peak. For 200 miles of Caspian Sea borderlands, the Elburz Mountains generally crest at over 10,000 feet. To the north, on the Caspian Sea coast itself, there is a temperate, year-round climate with abundant rainfall. The southern slopes of the Elburz are bordered by a desert having frigid winters and hot summers; the lower north-facing slopes have a lush, tropical-like forest. Above this lower forested zone another forest zone of oak, juniper, and poplar occurs up to about 8,000 ft. On the upper slopes there is a grassy cover reaching almost to the snow line. Operations at higher elevations in such mountains as the Elburz may require, besides cold weather gear, the use of special climbing equipment.

b. The Turkmen-Khorasan Mountains in northeastern Iran are a series of parallel, rounded ridges averaging 6,000 to 9,000 ft in elevation. They rise above the surrounding landscape like a continuous wall. Kuh-i-Binalud, a peak of these mountains, exceeds 11,000 feet. The Turkmen-Khorasan Mountains extend from the Caspian Sea 400 miles southeastward to the border of Afghanistan, forming for half of this distance the Iran-Soviet Union boundary. The valleys of these mountains are fairly heavily populated and cultivated, and produce a large portion of Iran's wheat.

c. Eastern Persian Highlands. Kuh-i-Taftan (13,262 ft), a volcanic cone, is the highest point in the Eastern Persian Highlands near the west Pakistan border. These highlands are a series of essentially parallel but discontinuous ranges with numerous elevations of 7,000 feet to 9,000 feet. Scrub and camel's thorn bushes grow on the lower slopes with scattered low trees above.

d. The Makran Mountains, a wilderness of dissected, rugged east-west ridges, flank the southe+rn Iranian coast on the Gulf of Oman for 300 miles. Bare rocks and sand dunes interspersed with date groves characterize the valleys. Peak elevations reach 7,000 feet.

e. Zagros Mountains. The 1,000 mile long Zagros Mountains are continuous and rugged, attaining widths of 150 to 200 miles along the whole western side of Iran. Mt. Sardeh (14,920 ft) is the highest peak, but there are many others between 10,000 and 12,000 feet.

f. The northwestern extension of the Zagros, covered by recent lava flows, merges with the Armenian Highlands of eastern Turkey and northwestern Iran. Here a series of giant volcanic cones tower above the broken plateau surface. Mt. Ararat (16,946 ft) is the highest cone, and another, Mt. Suphan, reaches 14,550 ft. Vegetation consists mostly of a sparse, scrubby growth at both lower and upper levels, the result of aridity at lower elevations and cold at higher elevations. Forests occur only at intermediate elevations. Most ridges and peaks exceed 6,000 feet. An extreme minimum temperature of -32 degrees F has

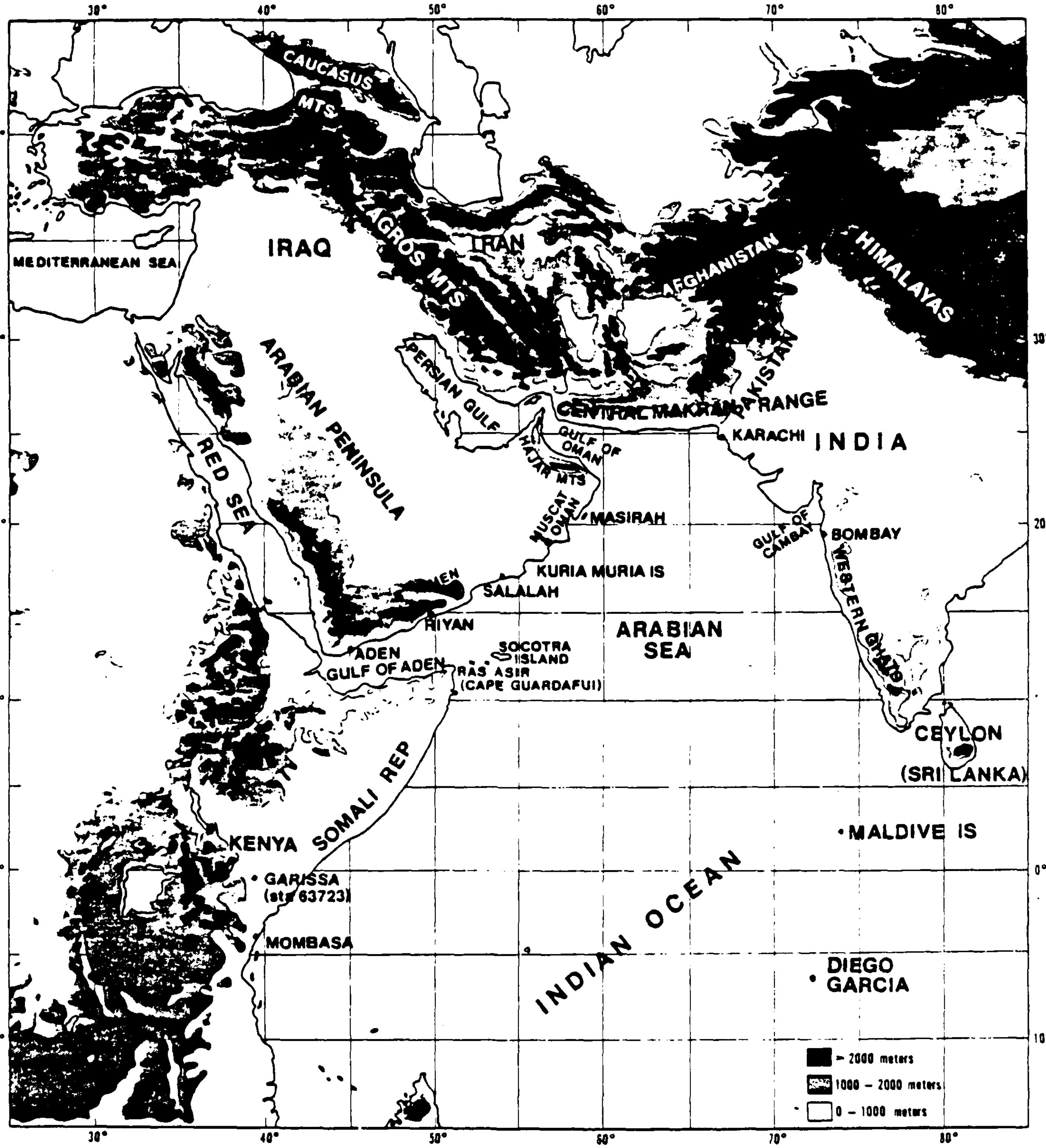

Figure 2

Major Topographical Features
of Southwest Asia

been recorded in this region at Kara, Turkey (elevation 5,700 ft).

g. Pontus Mountains. Elevations in the Pontus Mountains of Turkey rise to 7,500 feet within a few miles of the Black Sea coast. The north-facing slopes are covered with forests of beech and pine.

h. The Aegean Coastal Mountains section is marked by alternate strips of embayed valleys and low mountains which trend east to west. Most elevations are below 4,000 feet. The higher peaks have humid grasslands near their summits. Poplar and sycamore occur at intermediate levels. Short grass and brush with scattered small trees are found on the drier lowlands.

i. The Taurus Mountains, consisting of four separate ridges, extend along the Mediterranean south coast of Turkey where they form a very rugged coast line. Peak elevations approach 10,000 feet and deep valleys are prominent.

j. Mountains of Cyprus. The island of Cyprus consists of two east-west mountain systems separated by the dry, treeless Mesaoria Plain. Coastal marshes occur at both ends of this plain. The Kyrenia Range, which is a series of narrow, rocky, and low (1,000 to 2,000 ft) parallel ridges, follows the northern coastline for 100 miles. The most extensive and rugged Troodos Massif encompasses most of the southwestern part of the island, and includes the highest peak on Cyprus, Mt. Olympus, at 6,430 feet. Stands of pine, dwarf oak, cypress, and cedar cover the lower slopes in the Massif.

k. The Sinai-Lebanon Uplands consist of two roughly parallel ranges of mountains split by a deep linear depression which is occupied in north-south order by the Sea of Galilee, the Jordan River and its valley, the Dead Sea, and the Gulf of Aqaba. In the north, steep rocky limestone ridges vary in elevation from 4,500 to 8,000 feet. The highest peak, Kornet es Sauda (10,131 ft), is near Tripoli. To the south, irregular, sandy plateaus grade into a labyrinth of peaks and ridges in the Sinai Peninsula where Mt. Katherina rises to 8,650 feet. Nekhl, in the Sinai at an elevation of 1,300 ft, has a mean daily minimum temperature in January of 33 deg F. A good portion of the Sinai Peninsula is higher than Nekhl and, therefore, temperatures below freezing can be anticipated at night during the winter season at elevations above 1,300 ft.

l. The Nubian Upland of the eastern United Arab Republic (Egypt) is situated between the Nile River and the Red Sea. The Upland resembles in elevation and structure the southern extent of the Sinai-Lebanon Uplands from which it is separated by the Gulf of Suez. Rugged mountain ranges, with crests to 4,500 to 7,000 feet, are fringed on the west by rocky desert plateaus and wide sandy flat-floored wadies (valleys, gullies, or riverbeds that are dry except during the rainy season). Grasses and shrubs grow at higher elevations. Gabel Shayib (7,175 ft) is the highest peak.

m. Hejaz. The uplands east of the northern half of the Red Sea are known as the Hejaz and consist of greatly dissected escarpment with general crest levels of 2,000 to 3,000 feet, although peak elevations exceed 8,000 feet. In general, the crest elevations decrease towards the south.

n. Mountains of the Arabian Peninsula. The highest mountains (10,000 to 12,000 ft) of the Arabian Peninsula are found among the ranges of the Asir-Yemen Highlands which lie east of the southern half of the Red Sea. The highest peak, Jebel Hadhur Nebi Shi'Aib, located in Yemen, is 12,336 feet high. In their

interior the highlands consist of extensive plateaus at around 8,000 to 9,000 feet. Near their outer escarpments, the highlands are broken up into separate dome summits and jagged ranges. At San'a, Yemen (elevation 7,750 ft), an extreme minimum temperature of 17 deg F has been recorded. The southern margin of the Arabian Peninsula is occupied by the Hadramaut-Dhufar Uplands, a much dissected complex of barren mountain table lands. Average elevations of over 7,000 feet in the west decline gradually to 3,000 feet in the east. Heights approaching 10,000 feet occur in the South Yemen section of these highlands.

o. The Oman Mountains, extending along the western edge of the Gulf of Oman, are for the most part rugged and approach 11,000 feet maximum elevation.

1.1.2. Plains.

a. The Caspian Coastal Plain of Iran, 400 miles long, is narrow and backed by the Elburz Mountains. The warm, wet climate, a startling exception in Southwest Asia, supports luxuriant vegetation and rich harvests in this densely settled region (approx. 5 million population). Rice, cotton, tea, and citrus fruits are grown.

b. Mesopotamian Plain. The most extensive lowland in Southwest Asia, the Mesopotamian Plain, comprises the flood plains and deltas of the Euphrates and Tigris Rivers. Large irrigated areas, marshes and small forested tracts characterize most of the region. The northern part grades into rolling steppe land.

c. The Nile Valley, a flat flood plain 5-15 miles wide, is in many places on the east bordered by 1,000 foot escarpments of the Nubian Upland. The Nile Delta, a very flat alluvial plain, covers about 15,000 square miles. The irrigated areas of both the delta and the valley are subject to flood from August to November and may become quite muddy and marshy.

d. The Makran Coastal Plain on the Gulf of Oman is very low and from 1 to 25 miles wide. Mangrove swamps separate the damp sands near the sea from soft dry sand inland where vegetation is very scanty. Dangerous quicksands called "mins" are formed when the sun dries the surface while the soil below remains semi-liquid.

e. The Sharon-Philistia Plain, narrow to the north, increasing in width to 100 miles in the south at the Suez canal, skirts the eastern Mediterranean coast from southern Lebanon through the Sinai Peninsula. The precipitation gradient is from the north to the south.

f. Tihama. The coastal plain of western Saudi Arabia, known as the Tihama, is a sandy waste 30 to 50 miles wide.

1.1.3. Intermountain Plateaus.

a. The Anatolian Plateau of interior Turkey is largely a treeless steppe with hot, dry summers and cold, dry winters. One station, Mezere, at 3,500 ft elevation, has recorded an extreme maximum temperature of 100 deg F, and an extreme minimum of minus 8 deg F.

b. The Inner Persian Plateaus and Basins region occupies almost half of Iran. Great areas of salt or mud flats are segmented locally by low mountains

and hills. Travel is extremely difficult both in winter when temporary or playa lakes are formed, and in summer when heat hardens the surface to sharp crusted sheets of salt.

c. Sinai-Lebanon Uplands. A series of undulating hills (elevation approximately 1,000 ft) grades eastward from the Sinai-Lebanon Uplands into semiarid steppe, which merges with vast stretches of gravel and stone in the Syrian Desert and Steppe. Long, low ridges and sand dunes alternate with occasional dry wadi-beds and depressions of clay which are filled with water during winter, but are dry in summer.

d. Nejd. A broken surface of extensive lava fields, local depressions of sand, and a series of escarpments alternating with curving washes of sand and gravel form the Nejd (central Saudi Arabia). This central region of sand dunes and ridges connects two extensive sand-deserts, the Great Nafud in the north, and the Rub al Khali in the south. Both deserts support little vegetation and few inhabitants. The Rub al Khali, or "Empty Quarter", is the second largest sand-desert in the world, covering some 250,000 square miles. In the Rub al Khali, at Ubaila, a 10-day temperature record, taken during July 1954, showed that the temperature reached 120 deg F on 9 of the 10 days; moreover, on one day the minimum temperature was 100 deg F. The intense sun of these deserts suggests the need for protection against heat stroke, severe sunburn, and other heat related maladies.

1.2. Biotic Conditions of Southwest Asia.

1.2.1. Insects and Similar Pests.

a. Mosquitos and Flies. Among the various species of mosquitoes and flies are some of the most important carriers of insect-borne diseases (See Table 1). Anopheline mosquitoes can be found wherever there is a water supply. Breeding habitats exist not only in the swampy areas of the few perennial rivers and wadis of the desert, but also in remote villages or oases having irrigation systems, wells, rain-water cisterns, or small streams. Mosquitoes avoid places where temperatures are above 86 deg F, and 104 deg F temperatures are lethal to them. Temperatures below 60 deg F inhibit the development of the mosquito parasite (Plasmodium) which is the source of malarial infection. Mosquitoes are not normally found above 6,000 feet in Southwest Asia. Sanitary conditions, primitive by European or American standards, particularly in the villages and rural areas, promote the development of large fly populations.

Table 1

SIGNIFICANT INSECTS OF SOUTHWEST ASIA

INSECT	DISEASE CARRIED	REMARKS
Mosquitoes		
Anopheles	Malaria	Species breed in all types of water sources.
Aedes	Dengue	City breeder; can carry yellow fever in UAR, Iraq, Iran, & South Yemen
Culex	Filariasis, Japanese B. encephalitis, West Nile virus	
Flies		
Sand Fly	Sand fly fever, Leishmaniasis	Endemic May-Oct (skin ulcers).
Housefly	Mechanical carrier of intestinal, skin and eye diseases.	
Horsefly	Bites	
Fleas	Plague	Associated with rodents
	Endemic Typhus	Lebanon, Syria, & Iraq.
Ticks	Tick-borne relapsing fever Tick-borne typhus	Iraq, Syria, Jordan, Iran.
	Encephalitis (Russian spring-summer type). Rickettsial fevers	
	Tularemia	
Body Lice	Relapsing fever	
	Epidemic typhus	
Bedbugs	Mechanical carrier of diseases	Common in towns and villages.
Mites		Bites; causes skin rash Turkey, Syria, Lebanon

b. Ticks are abundant and widely distributed. Camel ticks are plentiful in Saudi Arabia, Iraq, and Iran. Fleas and mites, associated with rodents and similar animals, are common in urban and port areas.

c. The body louse, perhaps the most common of lice, is capable of transmitting epidemic typhus fever and a form of relapsing fever. The use of delousing powder for both clothing and body is recommended. Other pests include scorpions, centipedes, and spiders. Clothing and boots should not be left on the ground at night since scorpions and spiders move about at night and may take shelter in them. The stings of the scorpion and the black spider may produce intense local pain but are not likely to be serious.

d. Schistosomiasis (snail fever), an infection caused by a parasitic worm (fluke), is extremely common in Saudi Arabia, Iraq, and Syria. Infection can be contracted from larvae in the water by anyone wading, bathing, and drinking from, or wearing clothes in, irrigation ditches or other bodies of fresh water. Hookworms and roundworms, both of which usually gain access to the body through ankles and feet of anyone who walks without shoes on ground fertilzed with infected human excreta, are widely distributed.

e. Fungal infections of both scalp (mycoses) and feet (mycetoma) are prevalent among local population.

f. Military personnel, disciplined to field conditions and possessing inoculative immunity to the common endemic diseases, are not subject to the same health hazards as the local populace. Nevertheless, good sanitation measures, adequate personal hygiene, and awareness are necessary.

1.2.2. Poisonous Snakes.

a. Vipers: All vipers are easily recognized by the broad, flat head, narrow neck and elliptical eye pupils. Considerable variation occurs in general body color and markings. Colors range from grey to olive brown, and markings vary from longitudinal zigzag bands to rows of large spots. They inhabit most of the region except the more remote and barren desert areas of the Arabian Peninsula. Among the vipers, the blunt-nosed vipers normally can be found on upland hills well exposed to the sun, although they also inhabit marshy places. The sand vipers and horned vipers prefer the plains and rock-sand desert regions. Most species possess a venom of moderate toxicity that produces a great deal of local reaction (swelling, discoloration, dull pain), but seldom results in death.

b. Sand Rattlesnakes occur in all deserts from Iran westward to the United Arab Republic. They are mainly nocturnal in habits. Their poison is hemotoxic (blood poisonous). Their bites cause local swelling and incapacitate victims but are not commonly fatal.

c. Cobras, which are typically banded and spectacled on their hoods, are rare. However, because of their wide habitat range in the southern regions of Asia, and their adaptability to living at sea level as well as in the mountains, they should be considered. Although cobras are not usually aggressive and bite only when molested, their venom is dangerously neurotoxic to man (injurious to nervous system).

d. Sea Snakes: At least 9 species of poisonous sea snakes are found in

shallow coastal waters in the Persian Gulf. They are especially common in the vicinity of river mouths. They are generally inoffensive and seldom bite except when provoked through rough handling. The only known fatalities occured when they were brought up in nets and caught on hooks by fishermen. They resemble certain eels, with vertically flattened bodies and tails.

1.2.3. Harmful Plants.

a. General. The term "forest" in the sense of a continuous, dense growth of trees can be applied only to those areas where sufficient precipitation occurs, notably at higher elevations and in a pattern increasing in density northward. The predominant character of the vegetative cover elsewhere is that of low-growing shrubbery, thorn-bearing trees and plants, and prickly or burr-bearing grasses, all of which cause accelerated wear on body clothing and footgear. Leather gloves may be required when handling these plants.

b. Poisonous Plants. Several types of poisonous plants grow in the highlands of Southwest Asia. Both the low cactus-like tree, Euphorbia officinalis, and the oleander, Nerium oleander, exude a sap highly caustic to human skin; blisters result and these may become infected. Care should be taken to prevent bare skin from coming in contact with these plants.

1.3. GENERAL WEATHER AND CLIMATE.

1.3.1. SYRIA, LEBANON, JORDAN, AND ISRAEL.

a. General.

The combined area of Syria, Lebanon, Jordan, and Israel is located at the eastern end of the Mediterranean Sea between 29 and 37 Deg N and 34 to 42 Deg E. The area consists of coastal plains, a chain of mountains parallel to the coast, and a vast interior desert plain. The Rift Valley, oriented north-south, divides the southern portion of the mountains into eastern and western segments. The coastal plains and adjacent seaward-facing slopes have a Mediterranean type of climate, with hot,dry summers and mild, rainy winters. The desert interior has a dry continental type of climate with very hot summers and moderately cold winters. The climate of the mountains and valleys separating these areas may be characteristically Mediterranean or continental, depending on location and exposure. The primary climatic controls are the semipermanent pressure systems which develop over the Eurasian landmass and produce the predominant airflow patterns. Migratory pressure systems reach the area principally in September through May and are often attended by overcast skies, showers, and thunderstorms. Topography and the moderating influence of the Mediterranean Sea are also controls.

Mean daily maximum temperatures in the summer range from the 90s (degrees F) and the low 100s over most of the desert interior and the sheltered rift valley to the 80s and low 90s along the coast and in the mountains. Mean daily minimums in winter are usually in the 30s and low 40s over the desert interior and in parts of the mountains and are in the 40s and 50s elsewhere. The higher mountains of Lebanon have somewhat lower temperatures. Most locations in this area have recorded extreme high temperatures of 100 to 120 Deg F and lows below freezing. Relative humidities are highest (60 - 85%) during the early morning hours in winter throughout the area. Lowest humidity values occur during summer afternoons when they range from about 15 to 20% in the desert interior and the rift valley, to about 70% at some coastal locations. Mean annual precipitation ranges from less than 5 inches in the extreme south and over much of the desert interior to about 30 to 60 inches along the northern coast and in the mountains of Lebanon. Most of the precipitation falls in November through March; summers are almost rainless. Snow is most likely to occur in the mountains of Lebanon, where the highest peaks and ridges are snow-covered much of the time between November through March. At elevations below 2500 feet snowfall is quite rare. Thunderstorms are most likely in October through May. The average annual number of thunderstorm days ranges from 45 along the coast to less than 5 in southern portions of the area. Flash floods occur at times near the coast and to a lesser degree in the interior. Mean cloudiness ranges mostly from 30 to 70% throughout the area in winter, and from 20 to 40% near the coast and 10% or less in the desert interior in summer. Low ceilings are most likely to occur along the mountain slopes facing the Mediterranean during winter. Visibilities are generally good. They occasionally fall below 2 1/2 miles but rarely below 5/8 mile. The major restrictions to visibility are fog, haze, smoke, dust, and blowing sand. Westerly surface winds are persistent in the area except in winter and early spring, when directions are more variable. Wind speeds are moderate, although strong winds are frequently associated with thunderstorms and migratory lows. These lows occasionally intensify in the eastern Mediterranean, and accompanying winds sometimes cause extensive damage to coastal areas.

b. The Mediterranean coast region ranges in width from approximately 5 to 30 miles and lies generally between sea level and 500 feet. This region, exposed to the influences of the Mediterranean, experiences mild, rainy winters and hot, dry summers. Lows occasionally intensify near the coast, causing strong winds and high tides.

c. The western highlands region consists of a series of mountain ranges that parallel the coast. In the south, these mountain ranges are divided by the rift valley. The highest mountains are located near 34 Deg N, with the highest peak above 10,000 feet. Precipitation on the westward-facing slopes ranges from substantial in northern and central portions to light in the southern portions. The eastward-facing slopes, like the interior, receive scanty precipitation. The higher elevations are significantly cooler than the lower elevations (approx. 3 degree drop per 1000 feet) in this and other regions. Cloudiness is extensive in winter, but summer skies are generally clear.

d. The Rift Valley consists of a narrow north-south oriented valley, much of which is below sea level. It is hemmed in by mountains except at the southern end, where it opens into the Gulf of Aqaba. The region, shielded by mountains from the moisture-bearing westerly winds, receives scanty precipitation except in the north, where there is a break in the mountain range. Summers are excessively hot and dry, but winters are cool. In winter, skies are frequent-ly overcast in the north and partly cloudy in the south. In summer, there is very little cloud cover.

e. The Desert Interior is for the most part a sloping plain with scattered hills. Elevations generally range from 1000 feet in the north to 3000 feet in the south. In summer, the afternoons are extremely hot, but the nights are relatively cool, especially in the higher elevations. Winters are moderately cold, particularly in the northern portions. Precipitation is negligible in the south and very light in the north. Overcast skies are most likely to occur over northern portion in winter, and summer skies are generally clear. Relative humidities are quite low except in winter, when moist air is periodically brought into the area by migratory lows.

1.3.2. IRAN AND AFGHANISTAN.

a. General.

For the most part, Iran and Afghanistan have arid or semiarid climates. Only the Caspian coastal zone and some high mountain regions receive appreciable precipitation. Seasonal extremes of temperatures are marked. Summers are extremely hot except in the high mountains, and winters are cool or cold except in lower elevations in the south. During the winter, high pressure dominates over Asia. However, frequent passages of weather systems through the area bring cold dry air from the north, warm dry air from the south, and moist air from the west. During the summer, thermal low pressure prevails over southern Asia, producing hot, dry, and frequently dusty conditions in most of Iran and Afghanistan. Topographic features are very important modifiers of these large scale controls and they produce significant climatic differences.

Winter temperatures are pleasant in the southern coastal lowlands. The warmest region is the coastal plain of the Gulf of Oman. Here, the average temperatures range from the mid-50s and low-60s in the early morning to the 70s in the afternoon. Freezing temperatures have never been recorded along this

coast. Temperatures decrease northward, and at low elevations winters are coldest in north-central Afghanistan, where average temperatures range from the high-20s to mid-30s in the early morning hours to the high-40s and low-50s in the afternoon. Temperatures also decrease with elevation and, in the high mountains winters are very cold. Summers are hot at low elevations, where afternoon temperatures vary from the 80s along the Caspian Sea to over 110 degrees at the head of the Persian Gulf. Early morning temperatures during the summer vary from the 60s and 70s along the Caspian coast and in north-central Afghanistan to the high-70s and 80s near the southern coasts. In the high mountains, summer afternoons are cool and nights are cold. High humidity in combination with high temperature make summers very oppressive along the coasts, but elsewhere low humidity mitigates the summer heat to some extent. Throughout the year, the Caspian coastal zone is the most humid part of the area and the interior desert plains are the driest. Mean relative humidity ranges from as high as 95% on winter mornings in the Caspian coastal areas to as low as 10% on summer afternoons in the interior. Precipitation falls throughout the year near the Caspian Sea, particularly in the west where the mean annual rainfall exceeds 50 inches. In the rest of the area, most of the precipitation falls in the winter and spring, with the greatest amounts in the mountains. Large portions of the Zagros mountains and Afghanistan highlands average over 15 inches of precipitation, with some locations exceeding 30 inches. The interior desert plains and sections along the Gulf of Oman and in north-central Afghanistan receive less than 5 inches of precipitation annually. Much of the winter precipitation falls as snow in the northern latitudes and at high elevations. With the exception of the Caspian Sea area, all parts of Iran and Afghanistan have a high percentage of sunshine. The cloudiest time of the year is winter and most of spring except along eastern portions of the Gulf of Oman, where summer and early fall are cloudiest. Mean monthly cloud cover in winter and spring ranges from as much as about 80% near the Caspian Sea to as little as 20% near the Gulf of Oman. In summer and early fall, mean monthly cloudiness is less than 25% everywhere except along the Caspian Sea and the Gulf of Oman and in extreme east-central Afghanistan. Low ceilings are infrequent except in the north and in the high mountains in late autumn through spring and along parts of the Gulf of Oman in summer and early fall. Visibility is generally good. Major reductions in visibility are caused by dust and mirage in the most arid parts of the area and by precipitation and fog in the damper regions to the north. Surface winds are strongly influenced by topography, and diurnal variations in direction and speed are common. Thunderstorms occur mostly in the mountainous areas of the north during late spring and early summer and are generally infrequent elsewhere.

b. Topography and Geography. Iran and Afghanistan lie in the southern reaches of the temperate regions of Asia, extending between approximately 25 and 40 Deg N and from 44 to 75 Deg E. This area is a bridge between the Mediterranean climate to the west and the monsoonal climate on the east. Iran and Afghanistan consist mostly of rugged highlands and desert plains. The principal ranges are the Zagros mountains in western and southern Iran, the Elburz mountains in northern Iran, and the Hindu Kush, an extensive area of highlands in central and northeastern Afghanistan. Most of these mountain systems and many lesser mountain areas rise to over 6000 feet. Single peaks are over 14000 feet in the Zagros and over 18000 feet in the Elburz, and a few top 20000 feet in the Hindu Kush. The largest plains are the deserts in the interior. Foremost of these deserts are the Dasht-e Kavir and the Dasht-e Lut of central Iran, and the Khash Desert, the Dasht-i-Margo, and the Dasht-i-Poghdar of southern and southwestern Afghanistan. These desert plains represent

the lower elevations in the interior of this region. Smaller lowland plains are located along the Caspian Sea in northern Iran, along the Persian Gulf and Gulf of Oman in southern Iran, and in north-central Afghanistan. Much of the area has interior drainage and is characterized by many ephemeral or intermittent streams, intermittent salt lakes, and wet salt flats. There are few perennial river (rivers that flow year-round).

1.3.3. IRAQ AND THE ARABIAN PENINSULA.

a. General.

Most of Iraq and the Arabian Peninsula have an arid climate. Summers are extremely hot, dry, and almost cloudless, and winters are mild with only moderate cloudiness and little precipitation. The major exceptions are in the northeast mountains and sections near the south and southwest coasts. In the northeast mountains, winters are cool to cold and moderately cloudy with considerable precipitation, and summers are warm, frequently clear, and dry. Parts of the south and southwest coast get moderate rainfall throughout the year. However, the windward slopes of the higher mountains near the southwest coast get moderate amounts, generally in summer. Temperatures in the southern part of the Arabian Peninsula are high all year except in the mountains, where summers are warm and winters are cool. The primary climatic controls are the topography and the airflow patterns that are imposed on the area by the large semipermanent pressure systems that traverse the north in winter.

Mean daily maximum temperatures in summer range mostly above 100 degrees except near the coasts, where they are in the 80s and 90s, and in the high mountains, where they drop to the low 70s. Mean daily minimums in January, usually the coldest month, range mostly from the 30s to the 50s except on the south and the southwest coasts, where they range in the 60s and 70s, and in the high northeast mountains, where they probably drop below 20 degrees. Relative humidities remain high, mostly between 50 and 90%, all year near the coasts. In the interior, they are highest, between about 50 and 90% on winter mornings and lowest, about 10 to 20%, on summer afternoons. Mean annual rainfall is less than 5 inches everywhere except in the southwest and northeast mountains, where amounts approach 30 inches and 40 inches, respectively. Snow is frequent at high elevations in the northeast in winter. Summer cloudiness generally averages below 10% except in the mountains and in some sections of the south and southwest coasts where skies are frequently cloudy. In winter, mean cloudiness ranges from about 15% to 50% with the largest amounts occurring in the lowlands and foothills of the north and at isolated coastal sections in the south. In the high mountains of northern Iraq, winter mean cloudiness is estimated to be between 50% and 70%. Low ceiling are infrequent except in the high mountains and along parts of the south coast. Visibility is generally best in winter and poorest in summer, with dust, blowing sand, haze, and fog the chief restrictions. Northwesterly surface winds predominate in summer except near the south coast, where the southwest monsoon prevails. Although winds are quite variable in winter, northwesterlies are prevalent at many locations.

b. Topography and Geography. Iraq and the Arabian Peninsula cover nearly 1.4 million square miles and lie between about 12 and 37 Deg N and between 35 and 60 Deg E. The area consists largely of extensive arid plains that are bordered by hills and mountains in the northeast and southwest and to a limited extent to the southeast. The mountains in the northeast are along the borders of Turkey and Iran, with many peaks and ridges extending over 7000 feet and the

highest are to over 12000 feet. Those in the south and west rise abruptly in most places from narrow coastal plains along the Red Sea, Gulf of Aden, and Gulf of Oman to between 3000 and 9000 feet, with the highest peak near 12000 feet in the southwest. The plains are generally between 2000 and 4000 feet above sea level in the west, and they slope gradually downward toward the Persian Gulf. Part of these arid plains is gravelly or rocky, but a large portion is sandy. Extensive sand dunes are found in the Rub al Khali in the south.

1.4. CLIMATIC CONTROLS.

1.4.1. SYRIA, LEBANON, JORDAN, AND ISRAEL. The climate of these countries is principally controlled by the semipermanent pressure systems that determine the general circulation and, consequently, the predominant air masses over the area. Migratory pressure systems and fronts, as well as topographic, continental, and oceanic influences are also important. Latitudinal influences are comparatively small.

a. Major Semipermanent Pressure Systems.

During winter, high pressure develops over the Asiatic mainland and to a lesser extent over Europe, whereas pressures over the warmer Mediterranean are relatively low. The interplay of cold air from the north and east with warmer air from the Mediterranean Sea is largely responsible for the winter precipitation.

During summer, low pressure develops over the Asiatic landmass to the east. The resulting circulation causes hot, dry air to flow across the area. Therefore, precipitation is negligible and temperatures are high.

b. Air Masses.

Two air masses, polar maritime and polar continental, are dominant in winter. The polar maritime air masses usually have their origin over the North Atlantic and reach the area by crossing the Mediterranean basin. Polar continental air flowing out of Europe is also modified into polar maritime air over the warmer Mediterranean Sea. The amount of moisture in this modified air mass is not as great as that contained in the air masses arriving from the North Atlantic, and the precipitation that results is appreciably less. These two moist air masses are responsible for the winter precipitation and cloudy skies that characterize the coastal sections and adjacent slopes. The influence of the polar maritime air masses decreases inland, where polar continental air becomes dominant. The polar continental air masses, although originally cold over northern Europe and western Asia, are modified as they flow southward towards the area.

In summer, the predominant air mass, tropical continental, is part of the relatively weak circulation in the western portion of the Asiatic low. This air mass is hot and dry. It becomes relatively unstable over the desert interior during the afternoon, when local dust storms may add to the general hazy character of the air mass. Cumulus clouds are occasionally present during the afternoon. The moisture content of air is generally too small to produce cumulonimbus clouds and, consequently, thunderstorms. At night, with the cooling at the lowest layers, the air mass becomes relatively stable, and surface wind speeds decrease. A second air mass, tropical maritime, is occasionally present along the coast in summer. It is generally a shallow layer and seldom produces showers, although fog may form during the early morning. Hot, dry continental air is generally present above this shallow layer.

c. Migratory Pressure Systems and Fronts.

Migratory lows reach this area principally in September through May. They are most active in November through March, when most of the precipitation occurs. Although most of them originate in the western Mediterranean, a few

begin in the North Atlantic and also in the region immediately south of the Atlas Mountains in northern Africa. Many form as lee depressions, when relatively cold air moves toward the Mediterranean from Europe. The lows tend to travel along the associated cold front toward the Israel/Lebanon/Syria coast. The average annual number of lows reaching the eastern end of the Mediterranean is 28.

The intensity of these lows varies from weak depressions to severe storms with destructive winds. The amount of rainfall accompanying each storm is also highly variable. The more destructive storms are usually associated with pronounced cold fronts. The cold air that pours out of Europe behind these lows becomes very unstable as it flows across the warmer Mediterranean. The rate of movement is highly variable. Many of these storms move quite slowly, requiring several days to cross the Mediterranean. Occasionally, a low may remain stationary over the eastern Mediterranean, causing heavy showers. Blocking by a high pressure cell over eastern Asia is often the cause of these stationary lows.

Migratory anticyclones or highs seldom reach the Mediterranean basin. However, the cold air which pours out of Europe behind a low in winter causes a general pressure rise, particularly over interior portions of the basin.

During the winter season, the mean position of the polar front is over the Mediterranean and its eastern extremity extends into Syria and Lebanon. This front separates the polar air masses of Europe from the warmer air masses that overlie the Mediterranean Sea and northern Africa. Daily variations in the position of the polar front are associated with migratory lows and their accompanying fronts. Most of the instability associated with these lows occurs along and behind the cold fronts as the cold air moves onto the warmer Mediterranean. Thunderstorms are frequently associated with these cold fronts. The coastal plains and adjacent mountain slopes receive the full impact of the unsettled weather conditions.

Warm fronts usually accompany the migratory lows also. The warm air behind the front is often dry and contributes little to the rainfall to the area. However, because of the temperature contrast between the warm, dry air behind the front and the colder air ahead of the front, there is frequently much turbulence.

d. Topographic Climatic Controls.

The mountains, valleys, and elevated plateaus of this area are significant climatic influences. The mountains which parallel the Mediterranean coast are of primary importance. Moisture-laden winds from the sea deposit much of their moisture as they rise up the slopes. Because the air is quite dry as it flows downslope toward the interior, precipitation is scanty. Because of the higher elevation, those portions of the area above 5000 feet are relatively cool in summer and cold in winter; the highest peaks and ridges are snow-covered from November to March. The plateaus, with elevations mostly between 1000 and 3000 feet, experience large diurnal temperature variations. In summer, although the afternoons are excessively hot the early mornings are pleasantly warm. In winter, the afternoons are relatively warm, but the early mornings are quite cold. The Rift Valley, its floor mostly below sea level, is excessively hot in summer. The winds are also channelized north-south.

Except along the Mediterranean coast and on the adjacent seaward-facing slopes, the continental influence is predominant throughout the year. The degree of influence can be seen in the large seasonal and diurnal temperature changes and also in the generally scanty precipitation. The landmasses to the north and east, as well as the area itself, are the source of the dry, cool air masses in winter. The surrounding deserts are the source regions of the hot, dry air masses in summer.

The Mediterranean Sea, although a relatively small body when compared to the surrounding landmasses, is the source of much of the precipitation that falls in this area. The sea is also a temperature-moderating influence. In winter, cold air flowing across the Mediterranean is warmed before it reaches the area. In summer, cool onshore winds during the afternoon frequently alleviate the heat of the day. However, this sea breeze is generally limited to the immediate coast, with its influence decreasing rapidly inland. The Mediterranean also affects the stability of the air masses reaching the coast. In winter, cold air from Europe becomes unstable as it flows across the Mediterranean, but the warm air of summer tends to become more stable over the relatively cool water.

In winter, the amount of temperature increase to the south is small due to terrain; in the interior, the southern portions are higher in elevation and tend to be cooler, particularly during the early morning hours. In summer, there is little evidence of a latitudinal difference in temperature. In fact,the low-lying portions of the northern interior are hotter than the elevated southern portions.

1.4.2. IRAN AND AFGHANISTAN. The primary large-scale features which help determine the climate of Iran and Afghanistan are also semipermanent pressure systems, different types of air masses, migratory pressure systems, and cold fronts. Locally, a number of other factors alter and modify the effects of the major controls, resulting in climatic differences within this area.

a. Major Semipermanent Pressure Systems.

The vast Asian landmass is conducive to the formation and maintenance of high-pressure cells during winter. On average these highs appear as a large and intense semipermanent high-pressure area, the Siberian high, covering most of Eurasia. The region covered by the Siberian high is a source of cold, dry air and is largely responsible for the low temperatures of winter. The intensity and areal coverage of the Siberian high gradually decreases through the spring months, and thermal low pressure begins to appear over the southern part of Asia.

Intense heating of southern Asia by a nearly overhead sun results in maximum development of thermal low pressure in summer. Across Iran and Afghanistan, low pressure is a persistent daily feature throughout the summer and is responsible for hot, dry, and often dusty weather. The autumn months experience a change over from the mean pressure patterns of summer to those of winter. The thermal low loses intensity as the sun retreats to a more southern latitude, and the Siberian high begins to develop. During all seasons the mean pressure in a general sense decreases from north to south, resulting in a flow that is frequently northerly over much of the area. However, during winter and early spring the passage of disturbances often causes interuptions to this pressure pattern and distribution.

b. Air Masses.

The variability of air masses is greatest in late fall through early spring, when migratory pressure systems and fronts frequently produce changing weather patterns. Cold air masses enter Iran and Afghanistan from the Mediterranean region, eastern Europe, and central Europe, and central Asia. Those from the Mediterranean region and eastern Europe normally follow in the wake of depressions from the west. Air drawn into the area from the Mediterranean usually is not abnormally cold, but is relatively moist. Air from eastern Europe is colder because its origin is in higher latitudes and its trajectory is mostly over land, although some warmth and moisture are added to the lower layers over the Black Sea. Both of these air masses are potentially unstable and may result in cloudiness and, occasionally, in precipitation in the mountainous parts of western and northwestern Iran. Most of the moisture is depleted in these mountains, and fine weather usually prevails over the remainder of Iran and Afghanistan. Air masses that move southward from central Asia are the coldest and produce abnormally cold temperatures and mostly clear skies except along the Caspian coast. This very cold air becomes unstable over the Caspian Sea, causing cloudiness and precipitation on the coast and nearby mountain slopes. Warm, dry air masses from Iraq, the Arabian Peninsula, and Pakistan also affect Iran and Afghanistan at times during the colder part of the year. This type of situation occurs most frequently in the circulation preceding lows which move in from the west. Abnormally high temperatures are usually recorded, and dust and haze is often transported from the alluvial Tigris-Euphrates valley. The flow of air from the Persian Gulf and Gulf of Oman produces high humidity and possibly some cloudiness along the coast, but the nearby mountains block the shallow layer of humid air from advancing inland.

From late spring to early fall, almost all of Iran and Afghanistan is frequently under the influence of hot and very dry air masses that originate both in the area itself and in the surrounding countries as a consequence of the circulation associated with thermal low pressure. Hot, cloudless, hazy, and very dry weather is a persistent and monotonous feature of the summer in almost every section of both countries. However, along the Caspian shores, winds from the Caspian Sea cause humid and often cloudy and rainy weather. Also, in parts of extreme southeastern Iran and extreme western Afghanistan, relatively moist monsoonal air occasionally intrudes from the Arabian Sea and West Pakistan, respectively.

1.4.3. IRAQ AND THE ARABIAN PENINSULA. The climate of Iraq and the Arabian Peninsula is controlled by the circulations from large pressure systems, by migratory pressure systems and fronts, and by the rugged mountains within and adjacent to the area. Other important factors include the vastness of the area and the proximity of large bodies of water.

a. Major Semipermanent Pressure Systems.

In winter, the Siberian high is well established in central Asia, reaching its peak of development in January. Low pressure is centered in equatorial Africa. These pressure systems interact to produce an airflow pattern over Iraq and the Arabian Peninsula that may be generalized as northerly in winter.

In summer, an elongated thermal low is centered just east of the Persian Gulf and extends westward over the area. A ridge of relatively high pressure is

dominant north and northwest of the area. The resultant pressure gradient causes the general circulation over almost all of the area in summer to be northwesterly. The exception is along parts of the south and southwest coasts, where the southwest monsoon prevails. This stream of monsoon air, beginning as two separate flows out of the Indian Ocean and South Atlantic highs and merging over southwestern Ethiopia, reaches the southwestern part of the area as one flow. The boundary between the monsoonal circulation from the southwest and that from the northwest is sometimes referred to as the Inter-Tropical Convergence Zone (ITCZ). This zone is often broad and the winds within it may be quite variable.

b. Air Masses.

Air Masses over Iraq and the Arabian Peninsula are predominantly the dry, continental type. In winter, outbreaks from the Siberian high are always initially very cold and dry, but by the time the air reaches the area temperatures are usually well tempered, although not enough to preclude fairly frequent occurrences of freezing temperatures in sections north of about 25 Deg N. The initial dryness of this air mass is essentially retained in Iraq and in the northern parts of the Arabian Peninsula. Air from the Mediterranean is also frequently brought into the area in winter by eastward-moving low-pressure systems, but usually the moisture content is considerably depleted by the mountains bordering the eastern Mediterranean. On the whole, this air does not produce large amounts of precipitation except in the high mountains of northeastern Iraq. In winter, most of this area south of about 25 Deg N is persistently dominated by dry, continental air masses that are moderately warm.

In summer, nearly the entire area is within the circulation around the large Asiatic thermal low. This air is very dry and hot, resulting in desert-like conditions almost everywhere. The major exception occurs on the southwest mountains and parts of the south coast. Here, the southwest monsoon brings moist, tropical maritime air that causes considerable cloudiness and, on the windward slopes and ridges, occasionally heavy rainfall.

c. Extratropical Cyclones.

Lows frequently reach the eastern end of the Mediterranean Sea in winter and occasionally continue eastward across Iraq. However, in November and April, they effect Iraq and the northern part of the Arabian Peninsula less often than in the other winter months, and their centers generally follow a track to the north of Iraq. These lows and their associated frontal systems bring relatively moist air from the Mediterranean into the northern part of the area, to be followed by colder and drier air from Europe and western Russia. The amount of precipitation brought to the area by these migratory systems is limited because much of the moisture is lost in crossing the mountains that border the Mediterranean. Although the center of the low may pass to the north of Iraq, the trailing cold front usually extends southward into the area and sometimes reaches deep into the Arabian Peninsula. Part of the precipitation received is caused by the associated fronts. A feature of some of these migratory systems is the production of duststorms and sandstorms by the accompanying winds sweeping over dry, loosely packed surfaces. These storms may occur in either the warm or cold sectors of the systems.

d. Tropical Cyclones.

In a record of 70 years (1891-1960), a total of 137 tropical cyclones were observed in the Arabian Sea, but it is estimated that only 26 approached the Arabian Peninsula close enough to significantly effect it in terms of precipitation, cloudiness, or wind. Twelve of these storms brought winds of 48 to 63 knots to the southern coast of the Arabian Peninsula. In addition, 2 cyclones of this intensity passed near the island of Socotra and continued into the Gulf of Aden. On average, a tropical cyclone significantly effects the southern coast once every three years. The eastern half of the south coast is most vulnerable to these tropical cyclones, chiefly in May and October. The few which effect the western half are most likely in October and November. Tropical cyclones are a cause of rare heavy downpours on the south coast. When these cyclones move inland, although they normally travel only a short distance before dissipating, considerable flash flooding and damage may result.

e. Anticyclones.

Centers of high pressure seldom travel across or form in the area of Iraq and the Arabian Peninsula, but they are quite often sufficiently near to significantly affect the weather in winter. Those that form in or move across the area are usually confined to the period December through February. More often, highs are centered a considerable distance north of Iraq as they move eastward, and frigid air in their eastern periphery is drawn southward into the area. On occasion, the cold winds from these highs may extend deep into the Arabian Peninsula.

f. Topographic Controls.

(1) Terrain.

The mountains in and near Iraq and the Arabian Peninsula strongly influence the area's climate. The mountains west of Iraq that border the eastern Mediterranean extract much of the moisture from the air that flows eastward across them, particularly in winter. The mountains of Turkey and Iran often block cold air coming from the north and east that would otherwise reach the area in the colder months. Aside from the barrier effects, the air is warmed somewhat as it descends these mountains. The fact that the mountains in Iraq are the wettest section in the area is due essentially to the abrupt lift they provide to the moist air arriving with the migratory systems in winter. The rather substantial amounts of precipitation in parts of the southwest mountains of the Arabian Peninsula are also due to orographic lift of relatively moist air. Surface winds are also influenced by topography. In the mountainous regions, there are many local wind wind regimes that are almost completely independent of the general circulation patterns. The type of surface, largely barren and sandy, that exists in the area is also highly important. This type of surface is intensely heated during summer afternoons, resulting in extremely high air temperatures. It also cools readily at night under clear skies and produces relatively cool night air temperatures. Moreover, the loose sand and dust of the surface are easily raised by relatively light winds and reduce visibility.

(2) Continental and Latitudinal.

The great size of this area is highly important to its climate. Its vastness means that much of the interior is devoid of maritime influences as evidenced by the extreme aridity and large seasonal and diurnal temperature variations. The latitudinal extent of the Arabian Peninsula into the tropics has a significant influence on the temperature regime during the winter. Also, in winter the northern parts receive appreciable precipitation from migratory lows of the midlatitudes, whereas the southern extremities too far into the tropics to be affected by them.

(3) Oceanic.

In winter, most of the moisture that reaches the northern parts of the area comes from the Mediterranean Sea within the circulation of migratory pressure systems. However, the direct climatic influence of the sea is extremely small in summer. Although the Arabian Peninsula is bordered on three sides by water bodies, as a rule their influence on the climate extends only short distances inland. Some of the most obvious effects are the moderation of temperatures, increased cloudiness and rainfall, high humidities, and the occurrence of land and sea breezes near the coasts. The largest amounts of moisture from these waters arrive with the southwest monsoon in summer, but most of it is deposited as heavy rains on the windward slopes of the mountains fringing the southwest coast. Along the Arabian Sea coast, these winds generally flow parallel to the coast and, therefore, relatively little cloudiness and rainfall results from orographic lift. However, upwelling is prevalent in an area between 52 and 58 deg E which results from the winds blowing parallel to the coast and slightly off-shore, so the resultant wind-driven current moves away from the coast and cooler water is brought to the surface. At some places, low clouds, fog, and light rain or drizzle are common in summer as a result of the stabilizing effect the cool water has on the warm, moist air that passes over it.

Another important oceanic influence is caused by the excessive warmth of the Persian Gulf and the Red Sea. These are two of the warmest bodies of water in the world, with mean water surface temperatures exceeding 90 deg F over a large part of the Persian Gulf in July, August, and September and in the southern parts of the Red Sea in September. The high water temperatures result in great evaporation and, thus, very humid conditions in the air over these waters. At times this air is so moisture-laden that when one steps outside from an air-conditioned building the water vapor condenses on the exposed body surfaces in much the same way as it normally does on a cool object placed in a hot, humid environment. Further evidence of this excessive moisture in the air is seen by the condensation that occurs at night on metal roofs within a few miles of the shore. Condensation, or dew, has been known to be so intense at times to cause a substantial stream of water to flow into the roof's gutter late at night.

1.5. WEATHER PATTERNS.

There are basically four seasons associated with the monsoonal flow patterns over the Middle East/Arabian Sea:

a. Southwest Monsoon Regime (Jun-Sep).
b. Fall Transition Period (Oct-Nov).
c. Northeast Monsoon Regime (Dec-Mar).
d. Spring Transition Period (Apr-May).

Since these patterns play a major role in weather forecasting for the area, these four seasons will be used to divide the handbook's meteorological material for the area (i.e., climatology, forecasting rules/aids, synoptic features, etc.).

The fundamental cause of seasonal variations in monsoonal flow is large temperature gradients between land and sea. In addition, the shapes and topographical features of the continents surrounding the Arabian Sea, as well as variations in sea-surface temperatures, all interact to produce the unique features of the monsoon.

In the summer, intense heat lows develop over the land masses surrounding the Arabian Sea (Arabian Peninsula, southern Iran, Pakistan, and northern India) due to strong solar heating. The resultant pressure gradient establishes a low-level flow from water toward land which is known as the Southwest Monsoon. Upper-level flow is strong and from the east. In summer, the polar jet is mostly at higher latitudes and the Caucasus/ Zagros/ Himalayan mountain chain effectively blocks outbreaks of shallow colder air masses from northerly sources. Topographic features thus augment intensification of the heat lows and the intensity of the Southwest Monsoon so the heat low becomes the dominant weather feature. The Southwest Monsoon of the Arabian Sea is, therefore, much more intense than the Northeast Monsoon of winter. The effects of the African land masses during the summer differ from those in the winter. In contrast to winter, radiational cooling produces high pressure over the Kalahari Desert (located about 20 deg S over Africa). Radiational heating causes low pressure over the Sahara Desert and Arabian Peninsula, and the resulting south-north pressure gradient sets up a southerly flow across the equator. Because of upwelling off the Somali coast, the Southwest Monsoon is intensified further. Also affecting this cross-equatorial flow, with possible consequences to the entire monsoon circulation, is the phenomenon called the "low-level jet".

During the winter, the land masses (especially in the northern portions) are generally colder than the Arabian Sea due to the lower heat capacity of land relative to water. This establishes a low-level pressure gradient and results in a southward low-level flow from the land to the sea known as the Northeast Monsoon. Upper-level flow is generally westerly. Although cold air masses sometimes penetrate into this area, the mountain barriers block most intrusions, causing the land/sea temperature differences to be weaker than in the summer. The winds of the Northeast Monsoon are, therefore, generally weaker than those associated with the Southwest Monsoon. The African continent has the effect of causing the Northeast Monsoon to extend into the Southern Hemisphere. Radiatio-

nal cooling over both the Sahara Desert and the Arabian Peninsula, along with radiational heating over the Kalahari Desert, results in north-south pressure gradient at the surface across the equator over eastern Africa. As a consequence, a flow of air from north to south extending out to 400 nm off the coast sets up across the equator.

1.6. AFGWC FAME PRODUCTS

Perhaps the best products available for forecasting the weather in Southwest Asia are the AFGWC FAME teletype bulletins and facsimile charts. These products cover an area from 10 degrees South to 40 degrees North and bounded by 10 degrees East and 70 degrees East. The FAME KGWC is a 24-hour forecast chart valid 24 hours after the off-time data bases of 06Z and 18Z. The depiction of this chart is in two panels with the top panel being a horizontal weather depiction chart and the bottom a significant weather chart. Variables are the same as described for the FATR 1 and 2 in AFGWCP 105-1. Standard notation and symbology are used except that areas of blowing sand and suspended dust are depicted by a solid border. The teletype bulletin is transmitted twice daily at approximately 1500Z and 0300Z.

The teletype bulletin has three parts. Part A is a general synoptic discussion valid at 06Z or 18Z, including a brief description of significant surface/gradient level features and forecast reasoning and upper level patterns and features and their relation to surface features based on the 00Z and 12Z 250MB analysis. Part B breaks the area up into six sub-areas and discusses the weather features in a cause and effect manner in a sub-synoptic scale. Part C is a macroscale 48 hour outlook with discussion of the movement of major systems and resulting effects on the area.

FAME forecasters at AFGWC primarily use tropical analysis and forecasting techniques, starting with hand-streamlined analyses of both the low level (surface/gradient level) and upper level (300-100MB centered on 250MB data). These analyses rely heavily on continuity and total integration of satellite imagery. The forecasters discuss the numerical tool guidance with the AFGWC European Forecast Section to reach a consensus forecast maximizing the use of both data sets. This reduces the limitations of the continuity of streamline analysis over data sparse regions and the limitations of numerical guidance over weak gradient areas.

The AFGWC philosophy of analysis requires that fronts have thermal, jet, and vorticity support before being analyzed and forecast. Over the area covered by the FAME charts, many of the systems do not meet these classic requirements to be depicted as fronts. Therefore, they are often depicted as troughs or possibly shearlines to allow depiction of the associated weather without violation of the basic philosophy of analysis.

The FAME products are excellent tools for the forecaster in this area since most of the time one will find data sparse and forecasting difficult, especially if satellite imagery is unavailable at his or her site. As with any centralized product, however, forecasters must tailor these products for their local conditions. The guidance provided by the FAME products on systems moving into the area from the northwest is especially valuable since, for most forecasters in the theater, there is insufficient time to do a complete European analysis and get good continuity of movement on these systems. For forecasters in the United States with mobility commitment to Southwest Asia, looking at the FAME products

will greatly aid their understanding of the day-to-day weather they can expect.

2.0. SOUTHWEST (SUMMER) MONSOON (JUNE - SEPTEMBER)

2.1. General. The Southwest (Summer) Monsoon is characterized by strong surface heat troughs over the land areas - particularly over India, Pakistan, Iran, and Saudi Arabia.

a. Surface wind direction over the Arabian Sea during the Southwest Monsoon is normally well established by June. The rainy season, however, usually doesn't commence until later. The rainy season along the west coast of India normally starts as early as 1 June in southernmost India but as late as 2 July in Karachi. Surface winds reach a maximum in July with the highest wind speeds (up to 50-60 kt) reported northeast of Socotra Island located off the coast of the horn of Africa. Winds of greater than 33 kt occur here more than 30% of the time during the Southwest Monsoon. Due to the strong winds, sea heights of 8 ft or more persist over more than half of the Arabian Sea during this season. Winds up to 500 mb are predominantly westerly or southwesterly.

b. Upper-level winds (above 400 mb) are generally easterly during the Southwest Monsoon. The Himalayas help produce and anchor an intense upper anticyclone (high) near 30 deg N and 85 deg E. Between this high and the subtropical ridge of the Southern Hemisphere exist the most extensive and strong-est upper tropospheric easterlies within the tropics.

c. There is considerable variability in the time of onset, intensity, and time of ending of the Southwest Monsoon. During the transition periods the southwest winds are not persistent, they occur in periods separated by variable or even northeasterly winds. Fluctuations in wind speed intensity during the heart of the Southwest Monsoon are correlated to the distribution of the pressure gradient over the Arabian Sea and not with the central pressure of the heat troughs over the land. Careful monitoring of the low-level jet as it crosses the equator may help forecast intensifications of the summer monsoon.

2.2. "Onset" of the Southwest Monsoon.

Although weak southwesterly winds may appear in the latter stages of the Spring Transition, the start of the real Southwest Monsoon is usually signalled by a "burst" in the cross-equatorial wind flow (from south to north) near the surface. This increase occurs abruptly, then spreads in an orderly sequence. As this region of strengthening winds expands and progresses northeastward across the Arabian Sea, an area of enhanced convective activity sweeps toward the west coast of India. Cyclonic shear on the northern edge of the "surge" often leads to the formation of an "Onset Vortex". The onset may occur any time between mid-May and mid-June and is nearly always preceded by an intensification of the Southeast Trades over the southern Indian Ocean.

"ONSET" FORECAST RULES/AIDS:

A. SEQUENTIAL STEPS OF THE "BURST" OF THE MONSOON ARE:

1. INCREASE IN THE STRENGTH OF THE S.H. TRADEWINDS.
2. STRENGTHENING OF THE CROSS-EQUATORIAL FLOW.
3. SPEED INCREASE IN THE SOUTHWEST FLOW OFF THE NORTHERN AFRICAN COAST (FREQUENTLY ACCOMPANIED BY THE DEVELOPMENT OF AN AREA OF ENHANCED CONVECTION).
4. FORMATION AND DEVELOPMENT OF AN "ONSET VORTEX".
5. SHARP INCREASE IN THE PRECIPITATION ALONG THE SOUTHERN INDIAN COAST.
6. NORTHWARD SPREADING OF STRONG SOUTHWESTERLY FLOW TO EVENTUALLY COVER ALL OF THE ARABIAN SEA.
7. ESTABLISHMENT AND STRENGTHENING OF THE UPPER-LEVEL EASTERLIES.

B. SATELLITE IMAGERY CLUES:

1. LOW-LEVEL CLOUDINESS PARALLEL TO THE AFRICAN COAST (OFF SOMALIA).
2. MOVEMENT OF A CONVECTIVE AREA OR LINE NORTHEASTWARD ACROSS THE ARABIAN SEA.
3. THE DEVELOPMENT OF AN "ONSET VORTEX".
4. MOVEMENT OF THE "ONSET VORTEX" NORTHWARD TO ABOUT 20 DEG N AND THEN TOWARD THE ARABIAN COAST.
5. NORTHWARD PROGRESSION OF CONVECTIVE CLOUDS ALONG THE INDIAN COAST.

C. THE TIME PERIOD FROM THE INCREASE IN THE SOMALI JET TO THE ARRIVAL OF THE SOUTHWEST MONSOON OVER THE SOUTHERN INDIAN COAST IS 3-4 DAYS.

2.3. Basic Southwest Monsoon Flow.

There are two general types of flow based generally on the total amount of cloud cover and the intensity of precipitation over western India. These types are known as "weak" or "strong" monsoonal flow. In both cases, the total pressure gradient over the Arabian Sea is nearly the same. However, in weak situations the maximum gradient is found north of 23 deg N (mostly over land) and, in the strong situations, it is found over water (13 to 21 deg N).

GENERAL SOUTHWEST MONSOON FORECAST RULES/AIDS.

A. WHEN THE SOMALI JET INTENSIFIES, THE SOUTHWEST MONSOON FLOW OVER THE ARABIAN SEA (AND CLOUDS/RAIN OVER WESTERN INDIA) INTENSIFIES 1-2 DAYS LATER.

B. WHEN SUBTROPICAL CYCLONES (NOT THE SAME TYPE AS FOUND IN THE ATLANTIC OR MEDITERRANEAN) DEVELOP BETWEEN 700 AND 500 MB IN THE MONSOON TROUGH OVER THE BAY OF BENGAL OR THE NORTHERN INDIAN COAST, FORECAST LOW-LEVEL WIND FLOW TO INCREASE BY 10-20 KT OFF THE CENTRAL INDIAN COAST - PARTICULARLY IF THERE IS EVIDENCE OF THE CYCLONIC CIRCULATION PENETRATING DOWNWARD.

C. IF THE MAXIMUM SURFACE PRESSURE GRADIENT OCCURS NORTH OF 23 DEG N (OVER LAND), FORECAST "WEAK" MONSOON FLOW OVER THE ARABIAN SEA WITH MAXIMUM WINDS NEAR 2000 FT. IF THE MAXIMUM GRADIENT IS OVER WATER (13 TO 21 DEG N), FORECAST

"STRONG" MONSOON FLOW CONDITIONS WITH MAXIMUM WINDS ABOVE 3500 FT.

D. DURING "STRONG" MONSOON CONDITIONS, THE AREA NORTH OF 22 DEG N USUALLY EXPERIENCES RELATIVELY LIGHT SURFACE WINDS.

2.4. "Breaks" in the Southwest Monsoon.

"Breaks" in the Southwest Monsoon are the result of a breakdown in the entire monsoonal circulation pattern, including a weakening of the upper-level anticyclone over the Himalayas and the upper-level easterlies over the Middle East/Arabian Sea. Ramamurthy (1969) found that definite "breaks" in the summer monsoon occurred 68 out of 80 years studied. The longest breaks last 17 to 20 days, but the most frequent duration is 3 to 4 days. These breaks are most common during August.

"BREAKS" IN THE SOUTHWEST MONSOON FORECAST RULES/AIDS.

A. "BREAKS" DO NOT OCCUR WHEN TROUGHS IN THE MID-LATITUDE WESTERLIES (45-50 DEG N) MOVE UNIMPEDED ACROSS THE LONGITUDE BELT 90 TO 120 DEG E.

B. REGULAR DEVELOPMENT AND MOVEMENT OF LOW- TO MID-TROPOSPHERIC MONSOON DEPRESSIONS FROM THE BAY OF BENGAL ACROSS INDIA IS NOT CONDUCIVE TO CAUSING A "BREAK" IN THE SUMMER MONSOON.

C. DEVELOPMENT OF A BLOCKING HIGH BETWEEN 35 TO 70 DEG N AND 90 TO 115 DEG E IS FAVORABLE FOR CAUSING A "BREAK" OF THE SOUTHWEST MONSOON.

D. WHEN A "BREAK" STARTS TO OCCUR, FORECAST THE RAINFALL BELT NORMALLY NEAR 20 DEG N TO BE REPLACED BY ONE NEAR 25 DEG N WITH A SECONDARY BELT NEAR 7 DEG N. ALSO, FORECAST THE UPPER-LEVEL EASTERLIES TO WEAKEN (AND SHIFT NORTHWARD) AND THE LOW-LEVEL SOUTHWESTERLIES TO WEAKEN WITH THE NORTHERN BRANCH OF THE SOMALI JET BECOMING THE STRONGER BRANCH.

2.5. The Upper-Level Easterly Jet or Tropical Easterly Jet (TEJ)

The upper-level Easterly Jet or Tropical Easterly Jet, TEJ (known by both names) is an important part of the southwest Monsoon. Its intensity is directly related to the intensity of the upper-level Himalayan anticyclone, the occurrence and intensity of the mid-tropospheric monsoon depressions, and the intensity of the low-level southwesterly flow over the Arabian Sea. The TEJ is a result of the thermal gradient between the warm air over Tibet and the relatively cold air over the Equator and has a maximum at about 150 mb. The TEJ is persistent during the summer monsoon. Due to the extremely high temperatures above the continental heat lows, the pressure minimum decreases rapidly with height and becomes a pressure maximum above 500 mb. This maximum continues to intensify with height to the tropical tropopause, forming a strong anticyclone aloft. The strength and persistence of this upper-level feature result in relatively constant easterly winds in the upper troposphere and lower stratosphere over the area throughout the warm season. The mean position of the JET is above 40,000 ft near 10 deg N; however, some climatologies show a secondary maximum near the Equator in the central Arabian Sea. Wind speeds over 100 kt have been observed. Fluctuations appear to be directly related to changes in the strength of the

Southwest Monsoon flow, but quantitative (causal) relationships have not been established. Studies suggest the strength of the monsoonal flow may be related to anomalies in the upper-tropospheric westerly (mid-latitude) flow and the mean temperature in the subtropical ridge.

2.6. Climatology. The following is a list of valuable references:

A. National Intelligence Survey (NIS) Part 23 for the appropriate countries.

B. AWS Technical Catalog 85/001 for the latest RUSSWOs for locations of interest.

C. USAFETAC Data Summaries of Climatic Briefs - See AWS TC 85/001.

D. World-wide Airfield Climatic Data

Volume II Middle East
Part I AD-A002162
Part II AD-A002163

Volume IX Africa
Part I AD-682-915

E. World-wide Paradrop Data USSR, Asia, & Africa USAFETAC DS81/099 AD-A109-872

F. AWS Forecaster Memo -100 series listed in AWS TC85/001

G. Solar Data 5WWP/105-3 Volumes 3 & 4

H. Lunar Data 5WWP/105-4 Volumes 3 & 4

I. Follow on Training caramates - See AWS TC85/001

2.7. Arabian Sea - Regional Features.

a. Low-Level Clouds. The predominant types of low-level clouds found over the Arabian Sea during the Southwest Monsoon are Inversion-capped clouds and Convective clouds which break the inversion. From satellite imagery there appears to be a downward slope from east to west and from south to north across the Arabian Sea. The inversion tends to be higher and weaker during "strong" monsoon flow and lower and stronger during "weak" monsoon flow.

b. Low-Level Winds. During the summer or Southwest Monsoon, intense heat lows form over the desert areas surrounding the Arabian Sea. At the same time, high mountains to the north seal off the area from cold air outbreaks and mountains over eastern Africa present a barrier to low-level wind flow. As a consequence of these radiational and topographical features, strong southerly flow occurs along the African coast and a broad southwesterly flow dominates the Arabian Sea. The southerlies are the result of semipermanent pressure systems reinforcing each other, the Low in the Northern Hemisphere and a High in the Southern Hemisphere over Africa. The southerly flow parallel to the African coast causes a net transport of water off the coast which results in cold upwelling along the northern African coast (off Somolia). This upwelling is

very evident on mean sea-surface temperature charts. The upwelled water cools the overlying air and produces a local high pressure ridge which intensifies the pressure gradient between the coastal area and the heat low over the inland area and thus increases the southwesterly flow at the surface. Also, the upwelling produces a thermal wind component which increases vertical wind shear in the lower levels. All of these factors contribute to the formation and maintenance of a strong, relatively narrow wind stream (Somali Jet) along the African coast and a broad, persistent flow (Southwest Monsoon) over the Arabian Sea and its coastal areas.

c. Somali Low-Level Jet.

The Somali Low-Level Jet is a major component of the Asian summer monsoon and is maintained by semipermanent pressure systems reinforcing each other. This jet forms on the western boundary of a broad cross-equatorial current of moisture-laden air which feeds directly over the Indian peninsula during the southwest monsoon. The Somali jet is one of the strongest and most sustained low-level wind systems on Earth. Annually, the jet goes through a complete life cycle as the Asian Monsoon circulation, in which it is imbedded, evolves. After retreating into the southern Indian Ocean during the winter monsoon, the jet axis progresses steadily northwestward as the summer monsoon circulation develops. In the Southwest Asia area, the Somali Jet is normally present from April to October and is normally the strongest in July and August when maximum wind speeds up to 100 knots have been observed. By June, the low-level jet axis is located directly over the horn of northeast Africa (Somalia) and across the Arabian Sea to India. There are pronounced variations in the behavior of the jet on synoptic time scales and diurnal time scales as well.

The diurnal fluctuations of the jet include changes in wind speed and direction and also in the height of the jet core. Although the observational network in this area is sparse, research experiments in the area have provided invaluable data on the character of the jet. The jet core varies in height from about 500 feet to 1500 feet near the African coast and slowly rises to about 5000 feet across the Arabian Sea to India. There is strong vertical shear below the jet to the surface. Immediately after sunrise, wind speeds increase rapidly near the surface while decreasing in strength aloft. By late afternoon the winds are more constant with height except for a shallow surface shear layer. After sunset, the surface wind speed decreases and a nocturnal jet maximum remains aloft.

There are local speed maxima north of Madagascar, off the coast of Kenya, and to the northeast of Socotra Island (east of the horn of Africa). These are semipermanent features during the Southwest Monsoon. As with any large scale wind system, local effects of elevation, topography, and diurnal cycles can significantly influence the wind speed at a particular place and time.

When the Somali Jet is well developed, the Somali coastal area is usually characterized by clear skies. The clear area correlates well with cold upwelling shown in satellite IR data. The jet is not always a single core of high-speed flow, but is often made up of a series of segments. Changes in the intensity of the Somali Jet may be related to changes in intensity of the Southwest Monsoon. Studies have shown a direct correlation between maxima and minima in rainfall rates in western India with maxima and minima of the Somali Jet but with a one to two day lag time.

SOMALI JET FORECAST RULES/AIDS.

A. IN THE ABSENCE OF OBSERVATIONS, FORECAST CORE SPEEDS OF 50-65 KT AT AN ALTITUDE OF 500 TO 1000 FT NEAR THE AFRICAN COAST AND GRADUALLY INCREASING TO 5000 FT NEAR INDIA.

B. FLUCTUATIONS IN CORE WIND SPEED ARE ASSOCIATED WITH SOUTHERN HEMISPHERE COLD AIR OUTBREAKS (I.E., STRONGLY MIGRATORY HIGH PRESSURE CELLS). MAJOR FLUCTUATIONS CAN BE EXPECTED EVERY 2-3 WEEKS. CORE SPEEDS OF 65-80 KT ARE TYPICAL DURING INTENSIFICATION WHILE SPEEDS OF 30-45 KT ARE MOST COMMON DURING LULLS.

C. SOMALI LOW-LEVEL JET WINDS DO NOT SIGNIFICANTLY IMPACT AIR OPERATIONS ABOVE 10000-15000 FT. THE TEJ OR UPPER-LEVEL EASTERLY JET, HOWEVER, CAN INFLUENCE COMPUTER FLIGHT PLANS ACROSS THE ARABIAN SEA AND LOWER ALTITUDES MAY HAVE TO BE FLOWN TO COMPENSATE.

d. Upper-Level Clouds. Much of the Arabian Sea is characterized by subsid-ence in the middle troposphere which tends to suppress upper-level cloudiness. An exception to this rule occurs near the Indian coast where convergence in the low- and mid-level flow causes very heavy rainfall and considerable convective activity. The high-level easterly jet spreads moisture which is carried aloft by this convection downstream (westward) over the Arabian Sea. The result is frequently a dense cirrus shield which dissipates due to subsidence as you go westward. The amount/density of the cirrus deck is generally related to the intensity of the rainfall over western India.

CLOUD AND WIND FORECAST RULES/AIDS.

A. DENSITY AND WESTWARD EXTENT OF CIRRUS OVER THE ARABIAN SEA IS DIRECTLY RELATED TO THE INTENSITY OF MONSOON RAINS OVER INDIA. IN "STRONG" MONSOON FLOW, CLOUD COVER EXTENDS 500-700 NMI OUT TO SEA FROM THE INDIAN COAST.

B. THE AFRICAN COAST, PARTICULARLY IN THE NORTH WHERE UPWELLING IS STRONGEST, IS NEARLY CLOUD-FREE DURING THE SOUTHWEST MONSOON.

C. DISTINCT, CLOSELY-SPACED CLOUD LINES INDICATE RELATIVELY STRONG LOW-LEVEL WINDS.

D. CLOUD PATTERNS OVER THE ARABIAN SEA AND COASTAL AREAS PROVIDE THE FOLLOWING INFORMATION ON INVERSION HEIGHT.

1). CLOUD FREE EXCEPT FOR STRATUS - THE INVERSION IS NEAR THE SURFACE.

2). CONTINUOUS CLOUD LINE OR WAVE PATTERN - A STRONG LOW TO MEDIUM LEVEL INVERSION EXISTS (CLOUD-TOP TEMPERATURES FROM IR IMAGERY WOULD INDICATE RELATIVE HEIGHT).

3). CONVECTIVE CLOUDS - THE INVERSION IS WEAK OR NON-EXISTENT.

E. THE INVERSION (WHERE IT EXISTS) IS GENERALLLY HIGHER (LOWER) DURING "STRONG" ("WEAK") MONSOON CONDITIONS.

e. Visibility Restrictions. In general, visibilities over the Arabian Sea and surrounding land areas are lower during the Southwest Monsoon than during the Northeast Monsoon.

DUST. The southern portion of the Arabian Peninsula, the coastal areas of the Red Sea and the Persian Gulf and the horn of Africa (Somalia) contain areas from which dust may be carried aloft by the prevailing winds during the summer monsoon. Therefore, coastal areas (Africa and Arabian coasts, Gulf of Aden) are frequently affected by dust haze. It is most common from mid-June to mid-August in this area. Occasionally, the Gulf of Oman and the Makran coast will experience dust haze from local sources, but this usually limited to the period immediately preceding the onset of the Southwest Monsoon in the area. Besides causing restrictions to visibility, this dust can cause clogging of air filters, inlet ducts, etc. which can damage engines, electronic components, etc.

SALT HAZE. The combination of strong surface winds and low-tropospheric stability causes persistent salt haze over most of the Arabian Sea. Surface visibilities generally range 5-8 nm, depending on wind speed and inversion height. In the northern and western coastal areas where salt haze and dust haze often occur together, lower visibilities are common.

FOG. Unlike the fog which forms off the California coast due to upwelling, the cold upwelling off the Somali coast is not a major fog producer. This lack of fog is probably due to strong low-level divergence in the southwesterly flow which brings a strong subsidence inversion down to the surface, ensuring a supply of dry air adequate to prevent fog formation. Although atmospheric conditions are not conducive to the formation of dense fog, the sharp reduction of SST (Sea Surface Temperature) in coastal areas of the northwestern Arabian Sea causes moisture saturation in a shallow layer and contributes to poor visibility. The areas most often affected by lowered visibility or stratus are the windward shores of Socotra and the Arabian Coast between Riyan and Masirah Island. The period of occurrence and intensity is governed by the characteristics of the Southwest Monsoon (which causes the upwelling). The area near Salalah is particularly susceptible to low ceilings and visibilities; July and August observations at Salalah indicate that 60% of the reported visibilities are less than 2 miles.

RAIN. Although salt haze (and occasionally, dust) occurs in the eastern portion of the Arabian Sea, the principal visibility restriction is rainfall occurring during monsoon surges and convective showers. Visibility less than a half-mile is frequently observed for short periods.

VISIBILITY FORECAST RULES/AIDS.

A. IN COASTAL AREAS, VISIBILITY USUALLY REACHES A MINIMUM AROUND 0600 LOCAL TIME AND A MAXIMUM NEAR MID-DAY.

B. HORIZONTAL VISIBILITY OVER THE ARABIAN SEA IS GENERALLY REDUCED TO 5-8 NMI IN SALT HAZE. (DUST NEAR THE ARABIAN PENINSULA WILL CAUSE ADDITIONAL RESTRICTIONS BUT THIS VARIES WITH TIME AND LOCATION.)

f. Subtropical Cyclones. The most significant class of large-scale cyclonic circulation affecting the Arabian Sea during the summer monsoon is the

subtropical cyclone. This system is also called the "mid-tropospheric cyclone" because its circulation first appears in the mid-troposphere, although it may subsequently extend downwards and be detectable in the surface pattern. There are two types of subtropical cyclones. The first occurs in the eastern North Pacific and eastern North Atlantic during the cool season and is associated with cut-off pools of cold air aloft intruding into the subtropics from higher latitudes. Most mid-latitude forecasters are familiar with this type of subtropical cyclone. The second type occurs in the Arabian Sea area near the west coast of India during the summer monsoon. They develop between 700 and 500 mb in the upper level (monsoon) trough lying across the northeast Arabian Sea and are one of the major rainfall produces along the west coast of India.

When describing the subtropical cyclone, it is important to contrast the difference in the large-scale monsoon circulation between two regions: the Bay of Bengal (east of India), where monsoon depressions are frequent; and the Arabian Sea, where these depressions do not occur during the summer monsoon. This basic difference is found in the mean position of the monsoon trough over the Indian subcontinent. The vertical slope of the monsoon trough over western India and Pakistan is markedly less than over eastern India. For example, in July the mean trough position determined from the resultant wind field at 900 mb is at 31 deg N at 65 deg E and 24 deg N at 90 deg E. At 500 mb the trough is at 17.5 deg N at 65 deg E and 20 deg N at 90 deg E. Thus, at 65 deg E the slope is 13.5 degrees of latitude while at 90 deg E the slope is only 4 degrees. In a N-S cross-section in the eastern Arabian Sea, the trough disappears above 400 mb and a steady easterly regime prevails to the south of the subtropical ridge. A tropical easterly jet is evident in July near 100 mb south of 20 deg N, while a mid-latitude westerly maximum occurs north of 35 deg N near the 200 mb level.

In the subtropical cyclones in the eastern Arabian Sea, the cyclonic circulation is usually well developed at about 600 mb, while near the surface only weak evidence of circulation exists with, perhaps, a weak trough off the Indian coast. The temperature at 700 mb within the cyclone is usually colder than the environment, while at 500 mb it is warmer. Most severe weather and the greatest vertical cloud development occur to the west of the cyclone center.

Over the Arabian Sea, subtropical cyclones are the dominant weather producers during the summer monsoon and cause much of the summer rains in western India. While these cyclones are active, a heavy overcast extends westward out to about 500 - 700 nm from the west coast of India. The subtropical cyclones are related to enhancement of the southwest monsoon.

Several studies of the southwest monsoon (Ramamurthy, 1972; Jambunathan & Ramamurthy, 1974; and Monsoon Experiment MONEX, 1973) have led to the following conclusions:

(1) The maximum velocity of the low-level winds appears to be about 50 - 55 knots in both strong and weak monsoon conditions over the western Arabian Sea. This wind maximum is found in both cases at about 12 deg N between 55 and 60 deg E. During strong monsoons, however, the level of the wind maximum is about 900 mb, while during weak monsoons it is about 950 mb. This low-level wind maximum occurs just below, or in the layer of a pronounced low-level inversion.

(2) The effect of perturbations on the strong monsoon (i.e., subtropical cyclones) is to cause the intensification of the SSE-NNW pressure gradient over

the eastern half of the Arabian Sea south of about 20 deg N. This causes surface SW/W winds to be much stronger off the west coast of India during the monsoon conditions.

(3) The westerlies are strong through a much greater depth of the atmosphere in the eastern Arabian Sea during the strong monsoon.

(4) Variations in the strength of the low-level flow over the Arabian Sea are not correlated to the intensity of the heat low centered in Pakistan. During weak monsoon periods there is a wind maximum along the extreme NW corner of India with light winds to the south. On the other hand, during the strong monsoon conditions the westerlies are light north of 20 deg N and relatively strong along the remainder of the west Indian coast.

(5) Many, if not all, of the strong monsoon cases are caused by developing subtropical cyclones.

(6) Overcast conditions over the Arabian Sea extend westward to about 500 - 700 nm off the west Indian coast during strong monsoon cases. This increased cloudiness is attributed to the direct and indirect dynamical processes of the monsoon circulation rather than to orographical effects caused by the increased westerly flow crossing the Western Ghats (mountains along southwest Indian coast).

Since the subtropical cyclones are a low-latitude phenomena, few aids for forecasting their cyclogenesis are available. There may be a relationship to the monsoon depression of the Bay of Bengal. A significant incursion of deep moist air is a prerequisite for subtropical storm development and, since the subsidence over the Arabian Sea limits the supply of moisture from the west, cyclogenesis can only occur when moisture is available from the south or east. This condition is only met with monsoon depressions. Therefore, look for development of subtropical cyclones with increased rains, cloudiness, and surface winds in the eastern Arabian Sea during periods of monsoon depressions in the Bay of Bengal or northeastern India.

There are probably other processes that lead to increased intensity of the Arabian Sea monsoon and possible subtropical cyclogenesis. Forecasters should be on the lookout for other indicators to aid in forecasting this phenomena.

g. Tropical Cyclones.

Except during early June, tropical cyclones are rare in the Arabian Sea (and South Indian Ocean) during the southwest monsoon period. Tropical cyclones are more likely to occur during the spring and fall transition periods. Past records indicate an average frequency of occurrence of about every five years for cyclones to reach storm intensity. Of those that occur, most are located in the northeastern portion of the Arabian Sea, have tracks generally paralleling the west coast of India, and dissipate or make landfall east of 60 deg E. Recent satellite studies show that the frequency of tropical cyclones in the Arabian Sea may be greater than indicated by climatology, especially in the southwestern portion where virtually no data exists other than satellite data. There are no cases on record of a tropical cyclone with maximum winds of 34 kt or greater entering the Gulf of Oman or the Gulf of Aden.

Although tropical cyclones do not commonly occur in the Arabian Sea region,

they do have a significant effect on regional weather. Despite the infrequency of their occurrence along the Arabian coast where they influence the weather on the average of only once in three years, their associated torrential rains make up a significant part of the total rainfall. During a 25-year period (1943-1967), a quarter of the total rainfall at Salalah (located on central Arabian Sea coast of the Arabian Peninsula) was associated with tropical cyclones. Also, the winds and sea conditions associated with the tropical cyclones are the most dangerous single meteorological event affecting the Arabian Sea.

TROPICAL CYCLONE FORECAST RULES/AIDS.

A. CONDITIONS NECESSARY FOR THE FORMATION OF A TROPICAL CYCLONE ARE:

1). PRESSURE TROUGH OVER THE ARABIAN SEA NORTH OF 5 DEG N.

2). WEAK VERTICAL WIND SHEAR.

3). EXISTING LOW-LEVEL DISTURBANCE.

4). UPPER TROPOSPHERIC OUTFLOW.

B. WATCH FOR THE FORMATION OF A SURFACE CIRCULATION NEAR THE INDIAN COAST FOLLOWING THE FIRST SURGE IN THE LOW-LEVEL CROSS-EQUATORIAL FLOW; THEN, WATCH FOR THE DEVELOPMENT IN THE ENHANCED CONVECTIVE AREA AHEAD OF THE SURGE IN THE SOUTHWEST MONSOON.

C. NORMAL MOVEMENT OF THE "ONSET" TROPICAL CYCLONE IS NORTH ALONG THE INDIAN COAST, THEN CURVING WESTWARD TOWARD THE ARABIAN COAST. THE STRONGEST PERIPHERAL SURFACE WINDS ARE TYPICALLY FOUND SOUTHEAST OF THE SURFACE CIRCULATION CENTER.

2.8. Red Sea and Gulf of Aden.

Over the Red Sea and the Gulf of Aden, fluctuations in the Southwest Monsoon are less pronounced and much of the variability is due to diurnal and terrain effects.

a. Low-Level Features.

(1) Low-Level Clouds. The Red Sea is relatively cloudless during this season, particularly in the northern part. When clouds occur, afternoon cumulus predominate with bases mostly between 2000 and 5000 ft MSL. The area south of 15 deg N and west of 45 deg E experiences the greatest cloud coverage. When early morning low cloudiness exists in the Gulf of Aden, it usually dissipates by noon.

CLOUDINESS FORECAST RULES/AIDS.

IN THE GULF OF ADEN, MORNING LOW CLOUDINESS DECREASES SHARPLY BETWEEN 0800 AND 1200 LOCAL TIMES.

(2) Low-Level Winds.

The semipermanent low pressure systems over land and terrain bordering the

Red Sea cause extremely persistent winds from the northwest quadrant. In the Gulf of Aden, these same influences result in winds from the southwest quadrant. Winds speeds are usually less than 28 kt but occasionally exceed 28 kt near the northern end of the Red Sea and may reach gale force near the southern shore of the Gulf of Aden. In general, the wind direction is parallel to the long axis of both water areas. Near shore, the direction is usually affected by diurnal (land/sea breeze) forces which add an onshore component during the daytime and an offshore component at night. If the local terrain causes the diurnal influences to oppose/reinforce the gradient wind, significant speed variations can occur. For example, the additive effects can result in local wind maxima in the morning and minima in the afternoon. The southwest coast of the Gulf of Aden (Berbera) provides an example of this phenomenon.

As the persistent strong winds would indicate, sea heights in the Arabian Sea during the summer monsoon are high. Sea heights above 10 feet from June through August occur over 40% of the time. These figures may be on the low side since the USS CHICAGO reported sea heights 12 feet or greater (up to 17 feet) 80% of the time while stationed along the Somali coast between 4 July and 7 August 1974. Forecasters should be aware of these conditions for rescue and joint Naval operations in the area.

b. Upper-Level Features.

(1) High Clouds.

High clouds seldom occur over the northern two-thirds of the Red Sea in summer due to subsidence; however, the southern extremities of the Red Sea and the Gulf of Aden occasionally experience cirrus blow-off from thunderstorms or heavy monsoon storms in the eastern Arabian Sea. The latter effect is most likely to occur in July when the monsoon flow is most intense.

(2) Upper Winds.

The slope of the Monsoon Trough from a surface position over the Arabian Peninsula to a mid-tropospheric position over the horn of Africa results in a veering of the wind direction with height over the Gulf of Aden. The combination of terrain influences and low-level pressure gradient also produces a veering of wind direction with height over the Red Sea. Above about 20,000 ft, a broad band of easterly winds extends from about 30 deg N well into the Southern Hemisphere. The mean position of the axis of maximum wind speeds in the upper-level easterly jet is directly over the Gulf of Aden at altitudes in excess of 40000 ft. Maximum jet core speeds over 100 kt have been observed; however, in July over the Gulf of Aden they average about 65 kt. Variations in the wind direction of the easterly jet are small throughout the summer monsoon period, but significant wind speed changes occur. These changes appear to be directly related to the strength of the low-level Southwest Monsoon flow.

c. Visibility Restrictions.

(1) Dust and Sand.

The northern Red Sea experiences it best visibility during the summer monsoon. Dust storms are relatively infrequent and the only area where the visibility decreases to less than 5 nm more than occasionally is near the Gulf of Aqaba. In this area the visibility is below 2 nm about 5% of the time due to

LOW, BROWN DUST CLOUD. USUALLY THE SURFACE DUST/SAND CLOUD WILL NOT REACH A GIVEN POINT UNTIL AFTER THE LEADING EDGE OF THE CLOUD ALOFT HAS PASSED OVER THE POINT.

E. AIR TO GROUND VISIBILITY IS MUCH LESS THAN HORIZONTAL VISIBILITY IN THE PRESENCE OF DUST, DUE TO THE SCATTERING EFFECT ON SUNLIGHT.

F. SUSPENDED DUST IS DEPICTED ON SATELLITE VISUAL IMAGERY AS A HAZY VEIL. IR BRIGHTNESS IS AN INDICATOR OF THE ALTITUDE (TEMPERATURE) OF THE DUST CLOUD, BUT IS RATHER INACCURATE DUE TO THE EFFECT OF THE WARM SURFACE RADIATION WHICH PARTIALLY PENETRATES THE DUST CLOUD.

G. WHEN STRONG DUST STORMS ARE BEING REPORTED AROUND THE NORTHERN END OF THE PERSIAN GULF, FORECAST DUST HAZE TO CONTINUE ON FOR TWO DAYS LATER IN THE GULF OF ADEN AND SOUTHERN RED SEA.

H. THE DEVELOPMENT OF LARGE CONVECTIVE CELLS OVER COASTAL RANGES INCREASES THE PROBABILITY OF LOCAL DUST/SAND STORMS THAT EVENING.

d. Oceanographic Features.

Since there is no significant inflow of fresh water and very little rainfall, the Red Sea has a negative water budget; therefore, the salinity is extremely high. Salinity is usually lowest near the surface, exceeds 40 parts per million everywhere and generally increases toward the north at all depths. The unusual thermal/salinity structure creates anomalous sound propagation.

The geography of the Red Sea results in an unusual thermal stucture. Strong insolation throughout the year keeps the sea surface temperature (SST) above 25 deg C except in the extreme northern part where it occasionally drops below 22 deg C during the winter. Since the water is very salty, it sinks to form the bottom water for the entire basin. The temperature of the deep water is confined to a range of 21.5 to 22.0 deg C. The maximum surface temperature occurs in the southern Red Sea where the SST reaches 32 deg C. Thus, the vertical temperature variation ranges from zero in the north during the winter to about 10 degrees in the south during summer. The mixed layer ranges from 300 feet in the winter to less than 100 feet at the beginning of the summer monsoon.

The thermal structure of the Gulf of Aden is similar to that of the Arabian Sea except very near Bab al Mandab (near where the Red Sea and Gulf of Aden meet) where high-density water flows out of the Red Sea at still depth and descends the slope to a depth of nearly 5000 ft. This water is very warm and causes the 15 deg C isotherm to be depressed to a depth of more than 3000 ft, creating nearly isothermal conditions between depths of about 600 and 4000 ft. Considerable cold upwelling occurs near the entrance to the Gulf of Aden and, to a lesser degree, along the northern shore during the Southwest Monsoon.

2.9. Persian Gulf and Gulf of Oman.

The strong, semipermanent low pressure system which persists northeast of

this area is a controlling factor of the weather pattern during the summer monsoon period. Local diurnal effects are of secondary importance. Occasionally, subtropical cyclones, which are the most intense in the middle troposphere, migrate westward from India and affect the Gulf of Oman during dissipation stages.

a. Low-Level Features.

(1) Low-Level Clouds.

The Persian Gulf is virtually cloud-free during the summer. From the Straits of Hormuz the mean cloudiness increases toward the southeast and also with the season from June to August. In the vicinity of Jiwani, Pakistan, broken to overcast clouds occur nearly half the time in August. Ceilings below 1500 ft about 15% of the time, but the clouds tend to dissipate during the day, so that afternoon amounts are generally less than half those observed in the morning.

(2) Low-Level Winds.

The surface wind flow over the Persian Gulf and the Gulf of Oman is controlled by two basic air currents. One flows from the northwest parallel to the long axis of the Persian Gulf; the other is an extension of the broader Southwest Monsoon flow of the Arabian Sea. Both air currents tend to be persistent, especially in direction. The Gulf of Oman up to the Strait of Hormuz is normally the transition zone between these two currents. The results are northwesterly winds over the Persian Gulf, south to southwesterly winds near the entrance to the Gulf of Oman, and variable winds in between. The western approach to the Strait of Hormuz is usually characterized by southwesterly winds due to funneling. Local areas are subject to diurnal and terrain effects.

2.10. The Summer Shamal.

a. General.

From early June to mid-July, the Persian Gulf experiences what is known as the Summer Shamal or the 40-Day Shamal. Winds blow steadily from the northwest with few, if any, breaks. The heat low over Pakistan, a trough to the lee of the Zagros mountains, a semipermanent high pressure cell over northern Saudi Arabia and local terrain combine to create an enhancement of the low-level flow along the southwest shore of the Persian Gulf, particularly below 5000 ft.

At the surface, the Summer Shamal is often strong enough during the daytime to cause numerous dust storms over southern Iraq and northwestern Saudi Arabia. The wind speed decrease at night at the surface but do not decrease aloft. During the night under clear desert skies, radiational cooling causes a strong low-level inversion. The result is a very dangerous "nocturnal jet stream" with its core located only 1000-2000 ft above the ground. Wind speeds in excess of 50 kt have been repeatedly observed at 1000 ft over Bahrain with the most probable time of occurrence being between midnight and dawn (surface winds at the time are usually less than 20 kt). This nocturnal jet stream can be very hazardous to night aircraft landings at Persian Gulf airfields.

WIND FORECASTING RULES/AIDS.

A. WIND SPEEDS IN THE PERSIAN GULF VARY WITH THE STRENGTH OF THE LOW PRESSURE CENTER AND GENERALLY CHANGE GRADUALLY FROM DAY TO DAY.

B. WHEN GRADIENT-LEVEL WINDS ARE 25 KT OR MORE FROM THE NORTH OR NORTHWEST, EXPECT BLOWING DUST TO OCCUR ABOUT MID-DAY IF THE SURFACE INVERSION IS DESTROYED BY HEATING.

C. DURING THE SUMMER SHAMAL EXPECT A STRONG, LOW-LEVEL, NOCTURNAL JET (MIDNIGHT TO DAWN) TO OCCUR ON CLEAR, STABLE NIGHTS ALONG THE SOUTHERN SHORE OF THE PERSIAN GULF. WINDS AT THE 1000 FT LEVEL EXCEED 50 KT WHILE SURFACE WINDS ARE LESS THAN 20 KT.

b. Upper-Level Features.

(1) The Monsoon Trough slopes sharply southeasterly with height from a surface position near the Strait of Hormuz to a position over Bombay at the 500 mb level. The upper-level subtropical ridge extends eastward and west southwestward from a position near the northern end of the Persian Gulf.

(2) High Clouds. Except over the northern Persian Gulf where summer clouds are rare, high clouds reach a secondary maximum during July and August. Generally, these clouds consist of cirrus blow-off from monsoon disturbances occurring near the northwest Indian Coast.

(3) Upper Winds. North of the Monsoon Trough, winds generally veer from northwesterly to easterly with height. Near the northern end of the Persian Gulf, winds generally persist from the northwesterly quadrant below the 500 mb level. These winds are related to the Shamal and are strongest (up to 40 kt) at the lower levels (about 3000 ft), then decrease with height.

c. Visibility Restrictions.

(1) Dust and Sand.

In the northern 2/3 of the Persian Gulf, visibility reaches a minimum with the onset of the "40-day Shamal" in June. For example, Bahrain drops from well over 50% of visibility observations of 5 nmi or more in May to about 35% in June. Gradual improvement occurs in July and August. In the southern third of the Persian Gulf and in the Gulf of Oman, July is the worst month for visibility. Observations in the Gulf of Oman indicate that visibilities of less than 5 nm occur 10-15% of the time in July, but drop to less than 10% in August.

Dust storms over the land areas surrounding the Persian Gulf have start times that are influenced by diurnal changes in wind speeds. During the Summer Shamal wind speeds are generally light at night and free from convectional eddies due to the strong low-level inversion. As the inversion disappears one to two hours after sunrise, turbulence increases rapidly and surface winds exceed the critical dust-raising speed of about 16 kt. The winds then slack off again about 1800 L with a marked decrease in dust being carried aloft. Forecasters should be aware, however, that layers of dust raised during the day usually form a thin lens under the inversion, and the resulting layer of poor visibility at this level can persist for long periods of time. On the day after a major dust storm, visibility at the surface may still be less than 1 nm due to the settling of suspended dust.

VISIBILITY FORECAST RULE.

A. IF THE NIGHT SOUNDING INDICATES 1000 FT WINDS EXCEED 30 KT IN SUMMER SHAMAL CASES WITH STRONG LOW-LEVEL INVERSIONS AT NIGHT, RADIATIONAL HEATING WILL CAUSE SURFACE WINDS STRONG ENOUGH TO RAISE DUST THE NEXT DAY.

(2) Fog. Fog is extremely rare during the summer.

(3) Precipitation. Rainfall is rare during the summer season. Occasionally, subtropical cyclones will cause weak thunderstorm activity near the northern shores of the Gulf of Oman.

d. Oceanographic Features.

Since the Persian Gulf is very shallow, its thermal characteristics are much like that of a lake. The surface temperature reaches a winter minimum of 18 deg C in the northwest corner. This relatively cold, dense water sinks to form the bottom water of the Gulf which stabilizes at about 20 deg C during the summer, while the surface temperature increases to a maximum of about 33 deg C. The characteristics of the water in the Gulf of Oman resemble those in the Arabian Sea except on the narrow shelf near the approaches to the Strait of Hormuz where warm, high density water flows down the shelf slope depressing the 20 deg C isotherm to about 1000 ft. Weak upwelling occurs near Ras Al Hadd.

Except for the surface layer near the Strait of Hormuz, the salinity of the Persian Gulf ranges between 39 and 40 parts per million. The water which flows back into the Gulf of Oman has a salinity greater than 39 parts per million. Most of the water in the Gulf of Oman is more saline than that found in the Arabian Sea.

3.0. FALL TRANSITION PERIOD (OCTOBER - NOVEMBER).

3.1. General.

During the Fall transition period, the amount of insolation received over the Northern Hemisphere rapidly decreases causing the heat lows over the land masses to weaken and finally disappear. The Monsoon Trough retreats southward into the Arabian Sea and should more properly be called the "Near Equatorial Trough". In October, the surface winds over the Arabian Sea are mostly light and variable, but by November, light to moderate northeasterlies predominate - especially over the northern portion. In the upper troposphere the anticyclone which was located over the Himalayan Massif moves southeastward to the vicinity of the coast of Burma.

The result of these circulation changes is that the large-scale cloud cover reaches a minimum over the area. However, conditions become favorable for the development of tropical cyclones in the Near Equatorial Trough. Occasional cold fronts influence the northern Arabian Sea during the Fall transition period, but their effects are relatively weak and of short duration. Visibilities are generally good except around the tropical storms and in moderate dust storms associated with Arabian Peninsula cold frontal passages.

3.2. Large-Scale Circulation Features.

The Southwest Monsoon and the Northeast Monsoon are typified by persistent wind flow patterns with variations generally limited to changes in the wind speed. The transition seasons are periods of pattern reversal; directional and temporal changes are, therefore, maximized. This leads to somewhat meaningless mean values for such parameters such as winds, clouds, etc.

The flow reversals result from the rapid decrease in solar radiation which cools the lower troposphere causing the heat trough to be replaced by a cool ridge. As one pressure gradient regime disappears and the opposite is being established, relatively calm conditions with considerable short period variability predominate. In general, this is the most pleasant and benign season of the year. An exception to this rule is an increase in tropical cyclone activity.

3.3. Climatology. The following is a list of valuable references:

A. National Intelligence Survey (NIS) Part 23 for the appropriate countries.

B. AWS Technical Catalog 85/001 for the latest RUSSWOs for locations of interest.

C. USAFETAC Data Summaries of Climatic Briefs - AWS TC 85/001.

D. Worldwide Airfield Climatic Data

Volume II Middle East
Part I AD-A002162
Part II AD-A002163

Volume IX Africa
Part I AD-682-915

E. Worldwide Paradrop Data USSR, Asia, & Africa USAFETAC DS81/099 AD-A109-872

F. AWS Forcaster Memo - 100 series listed in AWS TC85/001

G. Solar Data 5WWP/105-3 Volumes 3 & 4

H. Lunar Data 5WWP/105-4 Volumes 3 & 4

I. Follow on Training caramates - See AWS TC85/001

3.4. Troughs and Frontal Systems.

During late September and early October, the heat lows disappear and are replaced by a weak high pressure regime. The Near-Equatorial Trough reforms with an eastnortheast - westsouthwest orientation between 10 and 15 deg N but migrates southward as the continental high pressure strengthens. A quasi-permanent, low pressure area over Sudan usually has a trough extending northeastward across the Red Sea.

As the transition to the Northeast Monsoon progresses, the Near-Equatorial Trough is forced southward to a position near the Equator by late November, and most of the Arabian Sea is influenced by weak to moderate northeast flow. The quasi-permanent East African low pressure area extends southward to straddle the Equator. A trough continues to extend northeastward over the Red Sea. Frontal passages start to influence the northwest portion of the area.

3.5. The Red Sea Convergence Zone.

As the Southwest or Summer Monsoon weakens and is replaced by the Northeast or Winter Monsoon, the wind flow in the Gulf of Aden and the southern Red Sea is reversed to become easterly and southeasterly, respectively. The continued northwest flow over the remainder of the Red Sea forms a sharp Convergence Zone in the southern part of the sea. As the Monsoon progresses, the zone drifts northward to a mean winter position near 20 deg N. This zone of convergence

migrates with the season and with synoptic changes but seldom retreats to the southern end and rarely advances all the way to the northern end of the Red Sea. It is usually marked by a distinct cloud band which is clearly visible on satellite imagery.

South of the convergence zone cloud band, surface winds are southerly and to the north they are northwesterly. The convergence zone itself is usually characterized by light, variable winds. Development of an anticyclone over the Arabian Peninsula will strengthen the southerly winds, forcing the convergence zone northward. The movement of a surface low from Sudan across the Red Sea results first in a northward migration of the convergence zone due to enhanced southerly flow and then a rapidly southerly movement as the cold surge penetrates southward behind the low center. This convergence zone persists until the latter part of the Spring transition period when southerly winds cease in the Red Sea.

3.6. Frontal Disturbances.

The southerly drift of the Subtropical Ridge permits intrusion of disturbances of extratropical origin. Although typical frontal passages are rare until late in the transition period, disturbance bands with time and space continuity occur in the Arabian Peninsula area (particularly over the Persian Gulf) with increasing frequency. They are often delineated by moderate to severe squalls with accompanying sand, dust, and thunderstorms. These disturbances seldom reach the Arabian coast but occasionally affect the Gulf of Oman.

TROUGH, FRONT, AND SQUALL FORECASTING RULES/AIDS.

A. AT LEAST ONE SEVERE SQUALL LINE (LOCALLY CALLED "UHAIMIR") SHOULD BE EXPECTED TO MOVE ACROSS THE PERSIAN GULF DURING THE OCTOBER - NOVEMBER TRANSITION PERIOD. GENERALLY COOLER AND DRIER WEATHER FOLLOWS.

B. "WINTER SHAMALS" START TO OCCUR IN OCTOBER AND NOVEMBER.

C. THE WIND DIRECTION OF THE WINTER SHAMAL IS GENERALLY PARALLEL TO THE SHORE LINES OF THE GULFS.

D. A FREQUENT FOREWARNING OF AN APPROACHING SHAMAL IS THE ARRIVAL OF A LONGER PERIOD SWELL ON THE WATER.

E. THE OCCURRENCE OF SHAMALS IS NOT DEPENDENT ON THE TIME OF DAY.

F. THE CONVERGENCE ZONE IN THE RED SEA IS USUALLY FORMED BY EARLY OCTOBER WHEN THE WINDS NEAR BAB AL MANDAB SHIFT FROM THE NORTHWEST TO SOUTHEAST. IT MIGRATES RAPIDLY TO ITS MEAN POSITION NEAR 20 DEG N.

G. THE CONVERGENCE ZONE IS USUALLY MARKED BY A CLOUD BAND WHICH IS EASILY RECOGNIZABLE ON SATELLITE IMAGERY.

3.7. Large-Scale Cloud and Wind Patterns.

a. The Arabian Sea.

The shift from the southwesterly to northeasterly surface flow usually becomes apparent first along the Arabian coast. Light variable winds appear in

the Gulf of Aden in September and along most of the Arabian Coast in October. As the pressure gradient over the northern Arabian Sea reverses direction (usually in October), and the Near-Equatorial Trough forms further south, winds become light northeasterly over the western portions of the Arabian Sea and north to northwest near the northern Indian coast. By late November, north to northeast winds spread over the entire Arabian Sea north of a line from the intersection of the Equator and the African coast to the southern tip of India. Throughout the transition season, land, and sea breezes strongly influence coastal areas, particularly where the terrain height increases rapidly near the coastline.

The most extensive changes in cloud patterns occur along and seaward of the Arabian and Indian coasts. As the Southwest Monsoon weakens, general low stratiform cloudiness near the Arabian coast is gradually replaced by scattered cumuliform clouds, and the time of occurrence of maximum coverage shifts from early morning to afternoon. Near the Indian coast, a temporary burst of enhanced convective activity usually accompanies the cessation of the persistent Southwest Monsoon flow; but, thereafter, the mean coverage is significantly less. Once the Northeast Monsoon has become established, overall cloudiness reaches a minimum, and convective activity subsides.

b. The Red Sea.

As the Southwest Monsoon weakens in September, the winds near Bab al Mandab become light and variable. Usually by the end of the month they have shifted to the southeast to form the convergence zone in the southern Red Sea. This zone then migrates northward during October to a mean position near 20 deg N. North of the convergence zone the winds remain northwesterly. The semi-permanent, low pressure trough associated with this flow provides a channel for passage of extratropical disturbances from the Sudan low across the Red Sea. As the disturbances transit the Red Sea, the convergence zone moves northward, then southward with the gradient changes. The convergence zone is usually marked by a recognizable cloud band.

Strong, gusty winds can occur in the Bab al Mandab in November. All coastal areas are strongly affected by diurnal effects; however, these effects are less noticeable in the areas of stronger flow. Strong convective activity is uncommon except when frontal zones penetrate the northern Red Sea.

c. The Persian Gulf.

The Persian Gulf does not have a monsoon climate; the prevailing winds are northwesterly throughout the year. Therefore, the transition period resembles other subtropical areas in that there is a gradual cooling and an increasing frequency of extratropical disturbances. The prevailing northwest wind becomes weaker and somewhat less persistent as the continental heat low dissipates. Extratropical disturbances crossing the Arabian Peninsula cause winds to shift to a southerly direction for periods of increasing length and frequency as the season progresses. These disturbances often bring cloudiness and occasionally rain to the area. They are principally responsible for the steady increase in mean cloudiness from its September minimum to a winter maximum. The "Winter Shamal" first makes its appearance during this season (occasionally in late September) and is usually accompanied by strong convective activity or dust or both.

d. CLOUD AND WIND FORECAST/AIDS.

(1) LAND/SEA BREEZES ARE USUALLY IMPORTANT DURING THE TRANSITION SEASONS, PARTICULARLY NEAR COAST LINES WITH STEEP TERRAIN GRADIENTS.

(2) LAND/SEA BREEZES ARE STRONGEST DURING PERIODS OF SETTLED WEATHER (I.E., MAXIMUM DAY-NIGHT TEMPERATURE RANGE).

(3) LAND/SEA BREEZE EFFECTS WILL MODIFY THE DIRECTION AND SPEED OF WEAK TO MODERATE GRADIENT WINDS BY ADDING AN ONSHORE COMPONENT DURING THE DAY AND AN OFFSHORE COMPONENT AT NIGHT.

(4) WINDS ARE WEAK AND EXTREMELY VARIABLE WITH A HIGH PERCENTAGE OF CALMS DURING OCTOBER AND NOVEMBER IN THE GULF OF OMAN.

(5) SEVERE SQUALL LINES (LOCALLY CALLED "UHAIMIR") CAN OCCUR IN THE PERSIAN GULF BETWEEN MID-OCTOBER AND LATE NOVEMBER. WIND SPEEDS OF STORM FORCE (GT 47 KT) HAVE BEEN RECORDED.

(6) MORNING FOG OFTEN OCCURS NEAR THE NORTHWESTERN INDIAN COAST DURING CALM CONDITIONS.

3.8. Tropical Cyclones.

a. Although tropical cyclones are relatively infrequent in the Arabian Sea area, those that do develop are found primarily in the fall and spring transition periods. Tropical cyclones in September and December are extremely rare and have erratic paths. Due to the few numbers of cyclones, the statistical paths for the cyclones may be suspect. Generally, it is observed that tropical cyclones south of 15 deg N move in a northwesterly direction well off the western coast of India. North of 15 deg N this track splits, with some moving westwards and others northward. If the tropical cyclone makes landfall, it is usually on the northern India coast. In 80 years of record, only one cyclone has entered the Gulf of Oman and none have made landfall on the Makran coast. Only about one tropical cyclone occurs per year (1.15 to 1.25 per year) and only a little more than half develop into tropical storms (.64).

b. FALL TRANSITION TROPICAL CYCLONE FORECAST RULES/AIDS.

(1) THE AVERAGE SPEED OF MOVEMENT OF ARABIAN SEA TROPICAL CYCLONES IS ABOUT 8.5 KNOTS.

(2) NEARLY ALL OF THE TROPICAL CYCLONES WHICH TAKE THE WESTNORTHWEST TRACK IN THE ARABIAN SEA ORIGINATE SOUTH OF 13 DEG N.

(3) SEA SURFACE TEMPERATURE (SST) IS NOT A LIMITING FACTOR FOR TROPICAL CYCLONE DEVELOPMENT IN THE ARABIAN SEA. (SST VALUES ALWAYS EXCEED THE CRITICAL LIMIT)

(4) TROPICAL CYCLONES MOVING ACROSS INDIA FROM THE BAY OF BENGAL MAY REINTENSIFY AS THEY MOVE OFFSHORE INTO THE ARABIAN SEA.

(5) SWELL FROM TROPICAL CYCLONES USUALLY PRECEDES ARRIVAL OF DAMAGING WINDS AND AFFECTS A MUCH LARGER AREA.

c. Tropical Storm Development.

Although some of the tropical storms have crossed the Indian subcontinent and regenerated in the Arabian Sea, the majority of tropical storms found in the Arabian Sea also develop there. Any mechanism for the development of tropical cyclones would have to explain the spring and fall transition maxima.

The prerequisites for development of intense tropical cyclones are:

(1) Sufficiently large sea or ocean areas with the temperature of the sea surface so high (above 26 deg C) that an air mass lifted from the lowest layers of the atmosphere (with about the same temperature as the sea) and expanded adiabatically with condensation remains considerably warmer than the surrounding undisturbed atmosphere at least up to the level of about 12 km. (Some evidence suggests that the absolute value of the sea surface temperature may not be critical, but rather the horizontal gradient of the sea surface temperature should be small over distances of several hundreds of kilometers).

(2) The value of the Coriolis parameter larger than a certain minimum value, thus excluding a belt of the width of about 5 to 8 degrees latitude on both sides of the equator.

(3) Weak vertical wind shear in the basic current, thus limiting formation to latitudes far equatorwards of the subtropical jet stream.

(4) A preexisting low level disturbance (areas of bad weather and relatively low pressure).

(5) Upper-tropospheric outflow above the surface disturbance.

These conditions are only met in the Arabian Sea when the Near-Equatorial Trough is found over the water north of 5 to 8 deg N (i.e., condition b above). The Near-Equatorial Trough is the large-scale trough of low pressure lying east-west between the subtropical high pressure belts of the Northern and Southern Hemispheres. The Near-Equatorial Trough then coincides with the warmest sea surface. There is a negative correlation between sea surface temperature change and 24-hour surface pressure changes (i.e., sea surface rises, surface pressure falls). The Near-Equatorial Trough does not move smoothly northward and southward with the sun. In fact, over the Arabian Sea, the Near-Equatorial Trough weakens and disappears in the Spring as a heat trough develops over the Indian subcontinent and reappears in Autumn as the land-anchored heat trough fills.

The annual variation in tropical storm development is as follows:

(1) During the winter monsoon, the northwest winds cause a relatively deep mixed layer in the Arabian Sea and, along with minimum solar insolation, a sea surface temperature minimum. Thus no surface trough is found north of the equator. By March, the Arabian Peninsula and India begin to warm, weakening the northeast monsoon. The ocean-mixed layer decreases and cloudiness decreases resulting in increased insolation and thus rapid sea-surface warming.

(2) With the Near-Equatorial Trough now (April) over the central Arabian Sea, tropical cyclone development and frequency increase. By mid-May, the heat low over Pakistan becomes dominant even though at times the Near-Equatorial Trough with associated tropical storm development is still found over the Ara-

bian Sea. With this heat low, the southwesterlies increase, causing the mixed layer to deepen, and as cloudier skies counteract increased solar radiation, the sea surface temperature falls to a minimum by August.

(3) With the surface trough (heat low) over land to the north of the Arabian Sea from late June to early September, almost no tropical cyclones occur in the Arabian Sea. By the start of Autumn the land is cooling and the winds, mixed-layer depth, and cloudiness decrease. Despite the opposing trend in solar radiation, the sea surface temperatures increase, resulting in a secondary maximum in October and November. Thus the Near-Equatorial Trough reforms over the sea and tropical storm development/activity reaches a secondary peak.

4.0. NORTHEAST MONSOON REGIME (DECEMBER - MARCH)

4.1. General.

During the winter season, the surface air over southern Asia is much colder than that over the sea. The resulting pressure gradient causes surface air to flow southward over the Arabian Sea. There are cold outbreaks into the Middle East/Arabian Sea throughout the season; however, the Himalayan and Caucasus Mountains block many of the cold surges from the Siberian anticyclone so that the Northeast Monsoon flow over the Arabian Sea is not nearly so intense as over the South China Sea.

During the Northeast Monsoon season, the principal trough in the tropics is the Near-Equatorial Trough of the Southern Hemisphere, but there is a weaker Near-Equatorial Trough east-west near 5 Deg N. North of the latter trough, surface winds are from the northeast and are generally less than 21 kts. They are frequently light and variable in the lee trough in the extreme northern Arabian Sea and Gulf of Oman. Fluctuations in surface wind flow are typically associated with cold air outbreaks from the north and west; these outbreaks are also the cause of the Winter Shamals over the Persian Gulf area. Cloud amounts are generally low and visibilities are good over most of the Arabian Sea and generally increase southward with a maximum in the northern Near-Equatorial Trough at about 5 Deg N. Clouds, rain, and dust are frequently associated with the stronger cold frontal passages in the northern part of the area. Tropical cyclones are practically nonexistent in the Arabian Sea during the Northeast Monsoon.

4.2. Large-Scale Circulation Features.

a. The upper tropospheric anticyclone which resides over the Himalayas in the summer continues to retreat southward forming one anticyclonic center over Africa and another in the western North Pacific (both between 10 and 15 Deg N). The upper tropospheric flow over all parts of the area north of 15 Deg N is westerly and quite strong at the tropopause level. The mean position of the Polar Jet is located south of the Himalayas and the higher Subtropical Jet is well developed over northern Africa and the Arabian Peninsula. During periods of normal upper air flow, cold air outbreaks from continental Europe and Asia are inhibited by the mountain barriers which border the region on the north. However, when large-amplitude perturbations occur in the Polar Jet, sufficent cold air is advected over the barriers to cause frontal surges to penetrate into the northern Arabian Sea. The most vigorous of these cold air outbreaks occurs with a blocking high over eastern Europe and a downstream trough over western Iran.

b. The strongest and most persistent cold surges occur in the last half of December, January, February, and early March. In November and early December, the upper westerlies are generally too far north for deep troughs to penetrate south of the mountains of Turkey - the cold surges during this period tend to be short-lived and relatively weak. In late March and April, on the other hand, while troughs in the upper westerlies frequently do reach well southward, the upper air flow tends to be neither sufficiently meridional nor sufficiently strong to advect cold air southward across the mountain barriers to the north. Also, strong heating of the cold air over the Arabian Peninsula causes the cold surges to rapidly weaken and die. These cold surges are known by several names;

shamal or winter shamal and western disturbances (Indian terminology). These will be discussed more later.

c. The time sequence of observations at Riyadh, Saudi Arabia, which should be representative of much of the Arabian Peninsula, shows oscillations in pressure, wind, and temperature with a period of 2-8 days during this part of the year. In general, falling pressure is associated with rising temperatures and southeast winds, wh_le rising pressure is associated with falling temperatures and northwest winds. The changes from southeast to northwest winds can be sudden like a cold frontal passage or gradual, as if a cyclonic center is passing nearby. Usually, the change from northwest to southeast winds is gradual, however. Clouds associated with these cold frontal type disturbances are usually middle and high clouds. Low clouds are fairly uncommon, except nearer the Persian Gulf where more low level moisture is available. Near the lows or troughs, the temperatures and dew points are usually above average and cumulonim-bus clouds can develop. Forecasters must use all the tools available to them to be alert for this potential since the sparsity of data makes forecasting a challenge. This is especially true if radar and satellite imagery are unavailable. You can often augment your available data by using aircraft reports and radar and approach control radar if available. The thunderstorms most often develop in late afternoon and continue into the night until about midnight. These storms can be accompanied by squalls, sudden temperature falls and pressure rises, and sometimes, duststorms. The latter can make visual observations of conditions especially difficult. Sometimes these disturbances can cause severe weather, strong winds, and hail, causing significant damage to valuable resources.

d. These disturbances can vary greatly in duration, intensity, and effects. The forecaster can best be prepared for them by watching the "big picture" as migratory systems move through the long wave pattern in Europe and the Mediterranean. This will provide early warning and allow for closer monitoring of the changing conditions as the disturbances approach.

e. Sometimes, the disturbances are accompanied by low level moisture which brings stratus and fog. This is most likely along the Persian Gulf coastal areas, but sometimes extends well inland. Often the wind shifts associated with the disturbances only extend upward to about 700 MB. Winds above show little change in direction with the passage of the disturbance. One factor which tends to enhance convective development is divergence aloft. Most cases associated with severe weather have had strong upper level divergence, strong surface heating, and a lower tropospheric inflow of moist air. This combination is conducive to deep convection in the tropics and the synoptic situation is similar to those where the subtropical jet stream is associated with severe weather elsewhere in the world. The vertical structure of the disturbances and 2-8 day periodicity are very similar to those in northwest Africa. In the southwestern portion of the Arabian Peninsula, a "dry line", similar to the "Marfa front" in west Texas, develops as a quasi-permanent feature. From October to May southerly winds are persistent over the southern Red Sea, especially at 850 MB, and may spill over the southwestern plateau. These winds are usually very moist. In strong contrast are the northeast to southeast winds of the interior which are extremely dry. Intersection of the "dry line" with these disturbances can enhance convective development.

f. A phenomenon known as the Aziab frequently occurs during the latter part of this period (March-April). It is associated with migratory low pressure

disturbances such as the Khamsin low coming from southern Egypt or a northeastward shift of the Sudan low. This phenomenon effects the western and southern portions of the Arabian Peninsula bringing hot, dry winds from the south with associated blowing dust. In the southern portions of the Peninsula it is known as Al-Ghoba and can bring thunderstorms with gale force winds. The Aziab is normally associated with Mediterranean depression moves which produce a low in southern Egypt. The Mediterranean low moves into Syria and northern Iraq while the Khasmin low travels toward western Saudi Arabia. The Aziab may be at times related to the winter shamal discussed later or may form when conditions are too weak to produce the shamal. The exact mechanism for the Aziab (or Khamsin lows) is not well understood; however, a baroclinic zone often exists in Algeria or Tunisia and frequent cold outbreaks may intensify the baroclinic zone forming the Khamsin low. The Aziab low will produce abnormally warm temperatures and may seriously restrict visibility due to dust storms. Hot, dry, and dusty weather can also occur in Egypt associated with the Khamsin lows.

4.3. Climatology. The following is a list of valuable references:

A. National Intelligence Survey (NIS) Part 23 for the appropriate countries.

B. AWS Technical Catalog 85/001 for the latest RUSSWOs for locations of interest.

C. USAFETAC Data Summaries of Climatic Briefs - AWS TC 85/001.

D. Worldwide Airfield Climatic Data

Volume II Middle East
Part I AD-A002162
Part II AD-A002163

Volume IX Africa
Part I AD-682-915

E. Worldwide Paradrop Data USSR, Asia, & Africa USAFETAC DS81/099 AD-A109-872

F. AWS Forecaster Memo - 100 series listed in AWS TC85/001

G. Solar Data 5WWP/105-3 Volumes 3 & 4

H. Lunar Data 5WWP/105-4 Volumes 3 & 4

I. Follow on Training caramates - see AWS TC85/001

4.4. Troughs and Fronts.

a. Although frontal systems pass over the Arabian Peninsula several times each year, the most common synoptic pattern during this season consists of high pressure centered over southern Asia with ridges over the Arabian Peninsula and North Africa. Inverted troughs commonly exist over the Persian Gulf/Gulf of Oman and across the central Red Sea. The typical surface pattern during the Northeast Monsoon consists of northeast flow over the Arabian Sea, weak and variable winds in the Gulf of Oman, strong southerly winds in the southern

entrance to the Red Sea, and a convergence zone in the central Red Sea. The storm track extends northeastward from the Mediterranean, and cold outbreaks are inhibited by the mountain ranges bordering the area to the north. The Near-Equatorial Trough is south of 5 Deg N except near the southern tip of India.

b. When low-latitude, upper-level troughs move over the area, a rather different pattern develops. The storm track extends more eastward, (sometimes southeastward) from the southeast Mediterranean or Egypt. As low centers track to the vicinity of the northern Persian Gulf, prefrontal (warm) weather usually occurs in the Persian Gulf and sometimes over the Gulf of Oman and the Makran Coast. As the trailing cold front is swept southward over the Arabian Peninsula, strong cold air advection west of the upper-level trough causes rapidly rising pressure. The resulting strong pressure gradient causes the Winter Shamal and often pushes the cold front well off the Arabian coast into the northern Arabian Sea. If the cold advection is very strong, the cold front will be forced southeastward into the Central Arabian Sea before the surface warming dissipates the air mass contrast. Weaker outbreaks often stall just off the Arabian Coast and result in a line of showery weather.

c. Common weather phenomena associated with the winter shamal are dust storms. Visibilities can drop to 2 miles or less (slant range reduced to less than 1/2 mi). The vertical extent of these dust storms can be 8500 feet or more and extend for hundreds of miles. High resolution satellite imagery is useful in determining the horizontal extent of dust storms.

d. TROUGH/FRONT FORECAST RULES/AIDS.

(1) WHEN A BLOCKING HIGH IS LOCATED NORTH OF THE ARABIAN SEA AND THE BAND OF WESTERLIES IN THE SOUTHERN BRANCH OF THE SPLIT FLOW IS WELL ORGANIZED, UPPER-LEVEL SHORT WAVES AND SURFACE FRONTS MOVE ACROSS THE ARABIAN PENINSULA.

(2) SURFACE WINDS OVER WATER AREAS ARE USUALLY STRONGER THAN THOSE REPORTED BY SHORE STATIONS FOLLOWING FRONTAL PASSAGES.

(3) WEAK SURFACE FRONTAL ZONES, WHICH ARE NOT WELL-DEFINED BY CLOUD PATTERNS OVER LAND, USUALLY SHOW INCREASED CLOUDINESS AND RELATIVE INTENSITY WHEN THEY MOVE OVER WATER AREAS.

(4) THE SURFACE REGION BELOW THE SUBTROPICAL JET (STJ) IS NORMALLY A FAIR WEATHER REGION; HOWEVER, WHEN A POLAR TROUGH "UNDERCUTS" THE STJ, A FRONTOGENETIC ZONE IS CREATED.

4.5. Regional Features - General. Although the Northeast Monsoon is the dominant feature during the winter months, considerably more variability occurs in this flow pattern than during the Southwest Monsoon. Most of this variability is due to the cold air intrusions resulting from the penetration of Polar Jet troughs south of the mountain barrier. The phenomenon affects the Red Sea, Gulf of Aden, Persian Gulf, Gulf of Oman, and the northern Arabian Sea. Each subregion exhibits typically distinct features largely related to geography and often having dimensions in the mesoscale range.

4.6. Arabian Sea.

a. Typical Frontal Systems. The very persistent anticyclonic flow centered on the Arabian Peninsula tends to perpetuate a frontogenesis zone extend-

ing northeastward from the East African low pressure area (Sudan Low). Extra-tropical disturbances cause perturbations in this zone to migrate across the Red Sea, Arabian Peninsula, and northern Persian Gulf. Normally these perturbations are not sufficently intense to cause a significant cold air outbreak over the Arabian Peninsula. Lacking strong cold air advection, the frontal zone fails to penetrate to the Arabian Coast.

When an upper-level long wave trough is positioned over the area, however, the northwesterly flow aloft advects cold air from the eastern European continental areas over the natural terrain barriers toward the Persian Gulf. As perturbations move into western Iran, subsidence raises surface pressure over the northern Arabian Peninsula. The resulting pressure gradient forces the frontal zone rapidly southeastward and, occasionally, into the Arabian Sea. Once over the warm Arabian Sea waters, the cold air mass is rapidly modified and seldom penetrates more than 100-200 nm beyond the coastline. Particularly strong outbreaks may, however, penetrate as far as a line from the Somali coast near Ras Hafun to the vicinity of Bombay. These stronger outbreaks usually carry considerable amounts of dust and cause extended periods of reduced visibility and particulate fall-out.

b. Arabian Sea Anticyclones. Climatologically, the Northeast Monsoon results from a persistent high pressure ridge which protrudes from the Asian anticyclone over the Arabian Peninsula and extends more or less continuously into the Arabian Sea. However, extratropical disturbances migrate across the northern part of the area in this season, and the normal high pressure ridge over the Arabian Peninsula is temporarily replaced by pressure much lower than that found over the northern Arabian Sea. The pressure pattern shifts the center of anticyclonic circulation to the Central Arabian Sea and results in southerly winds along the Arabian Coast and in the southern Persian Gulf (locally called "Kaus"). As these disturbances move into Iran, a high pressure ridge is reestablished over the Arabian Peninsula behind the front/trough. These fronts/troughs often stall near the coastline (either slightly inland or slightly offshore).

c. Cloud and Wind Patterns.

(1) Clouds. Overall cloudiness is relatively light and generally consists of scattered cumulus or stratocumulus, except in the fronts/troughs which occasionally influence the Arabian Peninsula and Makran coasts (vertical development here can be sufficient to cause showers). Based on satellite imagery, there is a semipermanent area of clouds which spreads south-southwest and south from a point near 20 Deg N and 65 Deg E. This pattern can exist for days at a time. This semipermanent cloudiness may be due to the cold dry air that travels toward the south over the northern Arabian Sea and picks up moisture from a source that is about one degree C warmer than the air, especially during the first half of the winter. This air mass is associated with cold surges following western disturbances (Shamal). The density of the cloud cover in this feature appears to be correlated with low-level wind speeds in the Northeast Monsoon flow.

(2) Winds. Winds from the northeast quadrant prevail over most of the Arabian Sea in this season. Exceptions are: (a) ahead of fronts/troughs which move off the Arabian Coast where south to southwest winds up to gale force occur for short periods of time and (b) along the coast of India where they are often from the north or northwest - particularly late in the season. The winds

are usually not as strong as they are during the Southwest Monsoon. Typical wind speeds are 10 to 20 kts. Stronger winds are usually associated with troughs/fronts. Near coast lines, both direction and speed are influenced by land/sea breeze effects; for example, afternoon wind speeds near Mombasa are much stronger than indicated by the pressure gradient due to the additive effects of the Northeast Monsoon and the sea breeze. Also, deviations from the predominant northeasterly flow often occur along the Makran Coast and in the Gulf of Oman. Under typical northeasterly flow a lee trough forms south of the coastal mountains of Iran and Pakistan, resulting in a zone of light and variable winds. Each month several trough/front passages occur preceded by southerly winds and followed by northwesterlies.

d. Equatorial Cloud and Wind Patterns. Cloudiness increases toward the south with the maximum occurring in the vicinity of the southern hemisphere Near-Equatorial Trough at about 10 Deg S. A secondary maximum is often found near a weak Near-Equatorial Trough at about 5 Deg N. Most of this cloudiness is typical of tropical convergent areas and may contain locally intense convective activity. Mean cloud coverage increases from west to east. Winds are light except in the tradewind band south of 10 Deg S and in an area off the southeast Somali Coast (Somali Jet) where the Northeast Monsoon penetrates to the Equator and beyond. Hazardous winds may be associated with thunderstorms.

e. ARABIAN SEA NORTHEAST MONSOON FORECAST RULES/AIDS.

(1) ALONG THE ARABIAN COAST, THE DENSITY OF STRATOCUMULUS IS DIRECTLY RELATED TO NEAR-SURFACE WIND SPEED (I.E., MORE AND THICKER CLOUDS CORRELATE WITH HIGHER SPEEDS).

(2) ALONG THE ARABIAN COAST, THE CLOUD AMOUNT INCREASES TEND TO PRECEDE SURFACE WIND INCREASES BY 6 TO 12 HOURS.

(3) ALONG THE ARABIAN COAST, WIND MAXIMA TEND TO OCCUR ABOUT 0300 AND 1300 LOCAL TIME. MINIMA ARE COMMON NEAR 0830 AND 1500 LT. THE DIURNAL EXTREMES USUALLY OCCUR AT 0830 (MINIMUM) AND 1300 (MAXIMUM).

(4) ALONG THE ARABIAN COAST, IF THE SURFACE WIND HAS NOT STARTED TO FRESHEN (OR PICK UP SPEED) BY 1000L, EXPECT RELATIVELY LOW WIND SPEEDS THAT DAY.

(5) AN UPPER-LEVEL TROUGH OVER WESTERN IRAN AND UPPER-LEVEL WINDS WITH A NORTHERLY COMPONENT OVER THE ARABIAN PENINSULA ARE NECESSARY CONDITIONS FOR MOVEMENT OF A COLD SURGE INTO THE ARABIAN SEA.

(6) LAND BREEZES ARE INTENSIFIED IN THE VICINITY OF LARGE RIVER VALLEYS OR STEEP COASTAL TERRAIN.

(7) CLOUD LINES WHICH FORM OFFSHORE DURING A COLD SURGE ARE USUALLY PARALLEL TO THE NEAR-SURFACE WIND DIRECTION.

(8) THE AFTERNOON SEA BREEZE STRONGLY ENHANCES THE NORTHEAST MONSOON NEAR MOMBASA, KENYA. NORTHEASTERLIES OF 18-25 KTS ARE COMMON.

(9) IN THE APPROACHES TO THE GULF OF OMAN, RAIN IS MOST COMMON WITH SLOW-MOVING COLD FRONTS. FAST-MOVING COLD FRONTS TEND TO BE DRY.

(10) BOTH LARGE SCALE AND LOCAL DUST STORMS OCCUR AROUND THE ARABIAN

SEA. LARGE SCALE DUST STORMS ARE CAUSED BY TURBULENT SYNOPTIC SCALE FLOW PATTERNS WHERE DUST IS CARRIED UPWARD SEVERAL THOUSAND FEET INTO THE ATMOSPHERE AND ADVECTED THOUSANDS OF MILES FROM THE SOURCE REGION. LOCAL SCALE DUST STORMS (AND SAND STORMS) OCCUR WHERE SAND DUNES OR DRY LAKE BEDS PROVIDE POINT SOURCES FOR SMALL SCALE DUST/SAND PLUMES TO BE RAISED BY LOCAL WINDS.

(11) IN THE COASTAL ZONES OF THE NORTHERN ARABIAN SEA, STRONG FRONTAL PASSAGES, PARTICULARLY WHEN DRY, CAN BE EXPECTED TO BE FOLLOWED BY MODERATE TO HEAVY DUST IN 3 TO 6 HOURS.

(12) UNLESS OBSCURED BY OTHER CLOUDS, APPROACHING DUST RESEMBLES DIRTY FOG AND USUALLY PASSES OVERHEAD BEFORE ARRIVAL AT THE SURFACE.

(13) LOCAL SCALE DUST STORMS SELDOM AFFECT OCEAN AREAS MORE THAN 60 NM FROM LAND.

(14) LARGE SCALE DUST STORMS SELDOM RESTRICT HORIZONTAL VISIBILITY OVER THE OCEAN AREAS TO LESS THAN 2 NM. HOWEVER, REDUCTIONS TO LESS THAN 7 NM MAY PERSIST FOR SEVERAL DAYS. THE BOUNDARIES OF LARGE SCALE DUST STORMS TEND TO BE QUITE DIFFUSE.

(15) LOCAL SCALE DUST STORMS MAY REDUCE VISIBILITY TO NEAR ZERO CLOSE TO THE SHORE AND THE LATERAL BOUNDARIES ARE FREQUENTLY SHARPLY DEFINED. THEIR OCCURRENCE IS NORMALLY ASSOCIATED WITH LOCAL TERRAIN.

4.7. Red Sea and Gulf of Aden.

a. General. Severe weather is infrequent in these regions during the winter season. In the northern Red Sea, weather is influenced by extratropical systems (frontal passages), but the lack of moisture sources and relatively strong solar heating tend to moderate the effects. The Gulf of Aden and the southern Red Sea are dominated by the Northeast Monsoon, but the direction of the flow is easterly in the gulf and southeasterly in the Red Sea due to the channeling effects of the terrain.

b. The Low-Level Convergence Zone. The formation of the Convergence Zone Cloud Band (CZCB) is a semipermanent feature during this season but may vary in position from the southern end of the Red Sea to near the northern end. The mean position is 20 Deg N. It moves up and down the Red Sea in response to the passage of extratropical disturbances from the eastern Mediterranean and northern Africa toward northern Saudi Arabia and Iraq. It persists near its mean position during undisturbed Northeast Monsoon flow. It is often well-defined on satellite pictures as a persistent cloud band or area which is usually more dense over water.

c. Low-Level Cloud and Wind Patterns.

(1) Clouds. Low-level clouds in the northern Red Sea are mostly associated with extratropical disturbances and are seldom heavy or persistent. Occasionally they produce light showers. South of the CZCB, broken or overcast stratocumulus is rather common during the night and early morning hours (particularly along the African shore). These clouds usually dissipate by afternoon. Gulf of Aden cloudiness is similar to that of the southern Red Sea, but the amounts are somewhat less.

(2) Winds. The winds in the Gulf of Aden and the extreme southern Red Sea are very persistent; the largest variation is diurnal. The direction tends to be parallel to the orientation of the basin but includes strong land breeze components - particularly near steep terrain. Gulf of Aden wind speeds average about 10 kts and winds over 20 kts are unusual; however, there is a strong funneling through the southern entrance to the Red Sea causing large speed increases in the northern approaches to the strait of Bab al Mandab. Average speeds throughout the strait in December and January approach 20 kt and are greater than 11 kt more than 80% of the time. Occasionally, winds here reach gale force. In the maximum wind region (vicinity of Hanish Islands), land/sea breeze effects are less noticeable due to the strength of the gradient and terrain-forcing effects. Wind speeds near the straits are somewhat less in February and March than in December and January.

Winds are increasingly variable northward of 15 Deg N due to the effects of extratropical disturbances moving across the northern Red Sea and southeast Mediterranean. Locations north of 20 Deg N have a high percentage of fresh northwesterly winds, but southerly winds ("Khamsin", "Aziab") are not uncommon in advance of transient low pressure systems. Coastal areas along the Gulf of Aqaba are known as one of the most windswept in the world. The CZCB is, of course, an area of light variable winds.

There is an important exception to the simple wind pattern normally associated with the northeast winter monsoon. This occurs in the extreme northern portions of the Arabian Sea and Gulf of Oman. Here, winds are generally light and variable. This phenomena may be associated with an induced lee, low pressure trough in the northeast flow as air crosses the mountain ranges of southern Iran and Pakistan.

d. High Level Cloud and Wind Patterns.

(1) Clouds. Middle and high cloudiness is uncommon during this season, and when it does occur, is usually associated with the Polar or Tropical Jet. When a Polar Jet trough passes through the region, the area between the trough line and the downstream ridge line usually experiences middle and high-level clouds (occasionally of sufficient density to produce rain). These cloudy areas have been typed (Brody,1977) according to shape and location relative to the polar trough. Occasionally, bands of high clouds with slight anticyclonic curvature will appear. Usually, these clouds are associated with the Subtropical Jet. They are easily identified on satellite pictures (very cold, striated, cast shadow on lower surfaces).

(2) Winds. The Subtropical Jet is important for flight operations in the region. The mean position of the core is north of the Arabian Peninsula; however, polar troughs transiting the Arabian Peninsula tend to displace it southward. The cloud banding mentioned earlier is useful in locating the horizontal position of the STJ on a given day.

e. Visibility Restrictions. Particularly vigorous cold fronts or Khamsin winds will raise enough dust to temporarily reduce visibility, particularly late in the season (February and March). These restrictions are usually confined to the northern two-thirds of the Red Sea and are, generally, of short duration (1 to 2 days). Fog patches may occur in coastal areas in the early morning hours, but are uncommon.

f. RED SEA/GULF OF ADEN FORECAST RULES/AIDS.

(1) A LOW-LEVEL CLOUDINESS MAXIMUM OCCURS IN THE VICINITY OF CAPE GUARDAFUI (HORN OF AFRICA) DURING THE NE MONSOON. TOTAL COVERAGE AVERAGES GREATER THAN 5 TENTHS.

(2) STRATOCUMULUS WHICH FORMS DURING NIGHT AND EARLY MORNING HOURS IN COASTAL AREAS USUALLY DISSIPATES BY MID-AFTERNOON.

(3) THUNDERSTORMS SELDOM OCCUR IN THE GULF OF ADEN DURING THE NE MONSOON.

(4) ONE OR MORE "MOISTURE FRONTS", WHICH MARK THE LIMITS OF MARITIME AIR SURGES, MAY EXIST SOUTH OF THE CONVERGENCE ZONE CLOUD BAND (CZCB). DURING A VIGOROUS SURGE, THESE BANDS RESEMBLE COLD FRONTS AS THEY MOVE SOUTHEASTWARD INTO THE GULF OF ADEN.

(5) DEPRESSIONS TRANSITING THE MEDITERRANEAN FREQUENTLY INDUCE A NORTHERLY, THEN SOUTHERLY DISPLACEMENT OF THE CZCB.

(6) AS PERTURBATIONS FROM THE SUDAN LOW MOVE NORTHEASTWARD ACROSS THE ARABIAN PENINSULA, WINDS IN THE CENTRAL AND/OR SOUTHERN RED SEA CAN INCREASE TEMPORARILY TO GALE FORCE.

(7) THE ENTRANCE TO THE GULF OF AQABA IS KNOWN FOR GUSTY WINDS. STRONG NORTHERLY WINDS RESULT IN MOMENTARY GUSTS WITH LARGE SPEED AND DIRECTION VARIATIONS.

(8) IN THE SOUTHERN RED SEA (SOUTH OF THE CZCB), STRATOCUMULUS COVERAGE IS GREATEST NEAR 0900 AND LEAST NEAR 2100 LOCAL TIME. IT IS MOST COMMON ALONG THE WESTERN SHORE.

(9) THERE IS A SEMIPERMANENT AREA OF LOW CLOUDS WHICH EXTENDS FROM THE VICINITY OF 20N 65E INTO THE GULF OF ADEN DURING MUCH OF THE NORTHEAST MONSOON.

(10) DUST STORMS ARE INFREQUENT DURING THE NE MONSOON SEASON EXCEPT IN THE NORTHERN RED SEA WHERE VIGOROUS EXTRATROPICAL DISTURBANCES CAUSE TEMPORARY STRONG, GUSTY WINDS.

(11) THE SUBTROPICAL JET CORE IS LOCATED OVER THE POLEWARD (NORTHERN) EDGE OF THE CIRRUS CLOUD BAND, AND SPEEDS IN EXCESS OF 100 KT AT 200 MB SHOULD BE EXPECTED WHEN:

(a) A HIGH-LEVEL CLOUD BAND EXTENDS WSW-ENE FROM TROPICAL TOWARD TEMPERATE LATITUDES, AND

(b) THE CLOUD BAND HAS A "STREAKY" APPEARANCE WITH A WELL-DEFINED NORTHERN EDGE AND A RELATIVELY CLOUD-FREE BAND JUST NORTH OF THE EDGE, AND

(c) A TROUGH IN THE WESTERLIES EXTENDS SOUTHWARD INTO LOW LATITUDES WEST OF THE CLOUD BAND.

4.8. Persian Gulf and Gulf of Oman.

a. General. In sharp contrast to the Red Sea, which is a narrow passage separating two prominent mountain ranges, the Persian Gulf and surrounding terrain form a broad basin with no significant barriers to air flow except along the Iranian coast. It is protected in the north from extratropical disturbances and cold air mass invasions by the mountain ranges of Iran and Turkey. Vigorous upper-air disturbances which penetrate to low latitudes are required to surmount these barriers. When these conditions are met, the potentially destructive Winter Shamal occurs; however, most of the time the weather conditions in this season are mild, sunny and, generally, uneventful.

b. The Winter Shamal (See NEPRF Technical Report TR 79-06, Perrone for more information). Shamal is an Arabic word meaning north and is also the name given to seasonal northwesterly winds that occur during the winter and summer in the Persian Gulf region. The characteristics of the two seasons' shamals are markedly different. The winter shamal is associated with mid-latitude disturbances that progress from west to east. It occurs following cold frontal passages and is characterized by strong northwesterly winds accompanied by such adverse weather conditions as thunderstorms, turbulence, low visibilities, and high seas. Although the winter shamal is relatively rare (winds in the Gulf region only exceed 20 kts less than 5% of the time in this season), it is operationally significant. The winter shamal sets in with such abruptness and force that its irregularly occurring gale strength winds are a sharp contrast to the normal light wind conditions. The summer shamal, in contrast, generally occurs with little interruption from early June through mid-July. Its occurrence, associated with the relative strengths of the Indian and Arabian thermal lows, is generally less significant than the winter shamal in terms of wind strength and accompanying weather conditions. Because of the greater potential for operational effects, the term shamal is usually understood to mean the winter event.

c. Synoptic Sequence of Events. An upper-level trough and its associated surface low pressure center and frontal system move eastward or northeastward from the eastern Mediterranean into Syria. Simultaneously, a second transient low center moves eastward from the Sudan Low across the Red Sea and the Arabian Peninsula. The resulting pressure gradient over the Persian Gulf causes moderate to strong southerly winds ("Kaus"in Arabic or "Shakki" in Persian) over the Persian Gulf which may reach gale force. These winds are strengthened by compaction of the pressure gradient along the Zagros mountains of western Iran. Seas under the southerly winds rarely exceed 8-10 feet due to the relatively short duration. These southerly winds bring thick, gloomy weather, often with considerable rain, along the Persian Gulf. As the cold front moves across the northern Arabian Peninsula, a new low pressure center typically forms on the front in southern Iraq or over the northern Persian Gulf. It eventually becomes the dominant low as the original low to the north and secondary low to the south weaken. As the upper-level trough moves into Iran, cold air is advected over the mountains of Turkey and Iran where it contributes to strong pressure rises west of the low. The resulting strong northerly (Shamal) winds force the cold front rapidly southeastward into the Persian Gulf basin. If the cold advection is sufficiently strong and the eastward movement of the upper-level trough is slow (usually satisfied by a blocking pattern), the cold front will continue to move off the southeast coast of the Arabian Peninsula and some distance out over the northern Arabian Sea. Weaker, faster-moving disturbances (more zonal pattern) usually result in the cold front becoming stationary near the southeast

coast of the Arabian Peninsula. As high pressure rebuilds over Iran, an inverted trough (occasionally a closed low) forms over the Gulf of Oman and extends northwestward along the eastern shore of the Persian Gulf. The final stage of the Shamal is a weakening of the high pressure center over the Arabian Peninsula (and a possible westward regression of the inverted trough).

d. Variations in the Sequence. The majority of the Shamal outbreaks continue for 24 to 36 hours. Occasionally (once or twice per year), the upper-level trough will stall in the vicinity of the Straits of Hormuz. The extended cold advection over the Arabian Peninsula will perpetuate the Shamal for 3 to 5 days. The strongest winds are normally associated with these occasions. Early and late in the season (October-November, March-April), small amplitude troughs result in similar sequences of events, but the limited cold air advection fails to push the front to the Arabian Coast. On these occasions, Shamal winds occur only in the northern portions of the Persian Gulf. If sufficient positive vorticity advection (PVA) exists aloft, a rather intense low may develop on the front in the central Persian Gulf, causing strong southerly winds in the southeastern portion.

e. Clear Air Turbulence (CAT). The same conditions which cause the Shamal may also lead to moderate to severe CAT. The areas normally affected by CAT are northern Saudi Arabia, Iraq, Iran, and the Persian Gulf. The strong wind shear near the jet maxima is likely to produce a complicated CAT pattern in both the vertical and horizontal directions. When the polar jet dips southward over, or just to the north of, the Persian Gulf in association with the onset of the shamal, a complex interaction between the polar and subtropical jets may occur. Sometimes, the two jets may overlay each other. Often, as the polar jet invades the Gulf region, it tends to depress the subtropical jet further southward. As the shamal sets in, a broadened and more intense turbulence area is likely, and the area's extent can be moved southward to coincide with the equatorward displacement of the subtropical jet. Additional complexity may be introduced by the generation of mountain wave conditions where the jet cores are nearly perpendicular to major mountain ranges. Moderate to severe turbulence can be expected downstream of the mountains in the region where the waves form from an altitude well below the height of the mountain peaks (sometimes down to the surface) up to as high as jet stream altitudes. The altitude range of the occurrence is a function of local atmospheric stability, wind speed and direction, terrain configuration, and vertical wind profile. Rough terrain will also produce moderate mechanical turbulence in the lower levels within the Shamal area.

f. SHAMAL FORECAST RULES/AIDS.

(1) FAVORABLE PRE-CONDITIONS ARE:

(a) COLD LONG-WAVE TROUGH (AT LEAST -25 DEG C AT 500 MB) SOUTH OF THE TAURUS MOUNTAINS OF TURKEY.

(b) EASTWARD MOVEMENT OF LONG-WAVE TROUGHS TOWARD THE LONGITUDE OF THE NORTHERN PERSIAN GULF.

(c) A CONDITIONALLY UNSTABLE ATMOSPHERE BASED ON SOUNDINGS FROM SOUTHEAST IRAQ OR KUWAIT.

(d) DAILY MEAN SURFACE TEMPERATURES AT LEAST 10 DEG C COLDER IN THE UPPER EUPHRATES VALLEY (I.E., STATION 40045) THAN AROUND THE NORTHERN GULF (I.E., KUWAIT; STATION 40372).

(e) A BLOCKING RIDGE FOUND OVER CENTRAL OR EASTERN EUROPE.

(f) SURFACE CYCLOGENESIS OCCURRING OVER THE TIGRIS-EUPHRATES VALLEY OR THE NORTHWESTERN PERSIAN GULF.

2. ONSET INTENSITY AND DIRECTION:

(a) IF ΔT IS THE AVERAGE SURFACE TEMPERATURE DIFFERENCE BETWEEN THE CENTRAL PERSIAN GULF AND THE TIGRIS-EUPHRATES VALLEY (NORTHERN IRAQ, EASTERN SYRIA), THE AVERAGE ONSET WIND SPEED WILL BE:

30 KT FOR ΔT = 10 DEG C

35 KT FOR ΔT = 15 DEG C

40 KT FOR ΔT = 20 DEG C

45 KT FOR ΔT = 25 DEG C.

(b) AVERAGE GUSTS WILL BE ABOUT 10 KT GREATER AND PEAK GUSTS ABOUT 15 TO 20 KT GREATER THAN THE AVERAGE SPEEDS SHOWN ABOVE.

(c) THE ONSET IS INDICATED BY A SHIFT IN WIND DIRECTION FROM SOUTHERLY TO NORTHWESTERLY.

(3) DURATION:

(a) IF UPPER-AIR PROG CHARTS INDICATE RAPID TROUGH MOVEMENT WITH NO STALLING NEAR THE STRAIT OF HORMUZ, FORECAST A SHAMAL DURATION OF 24-36 HOURS.

(b) IF UPPER-AIR PROG CHARTS INDICATE SLOW MOVEMENT AND POSSIBLE STALLING OVER THE STRAIT OF HORMUZ, FORECAST A SHAMAL DURATION OF 3 TO 5 DAYS. (WIND SPEEDS OVER THE SOUTHERN PERSIAN GULF AVERAGE 35-45 KT IN THESE CASES.

(4) CESSATION:

(a) FORECAST A 3 TO 5 DAY SHAMAL TO BREAK BY SUNSET ON THE DAY THE UPPER-AIR TROUGH MOVES OUT TO THE EAST OF THE GULF OF OMAN.

(b) IF A CONVERGENCE CLOUD BAND CAN BE SEEN OFF OMAN IN MORNING SATELLITE PHOTOS, FORECAST THE SHAMAL TO END THAT EVENING.

(5) ASSOCIATED SEA CONDITIONS:

(a) IF THE ONSET WIND SPEED IS COMPUTED FROM B(1) TO BE 30 TO 40 KT, FORECAST THE FOLLOWING SIGNIFICANT WAVE HEIGHTS:

10-12 FT IN 12-24 HOURS AFTER ONSET

12-14 FT IN 24-36 HOURS AFTER ONSET

15-18 FT IN THE SOUTHERN PERSIAN GULF (PARTICULARLY OFF THE QATAR PENINSULA) IF THE SHAMAL LASTS MORE THAN 36 HOURS.

(b) FOR A 3-5 DAY SHAMAL, FORECAST RESIDUAL SWELL HEIGHTS AS FOLLOWS:

6-8 FT THE DAY AFTER THE SHAMAL BREAKS

3-5 FT ON THE SECOND DAY AFTER

1-3 FT ON THE THIRD DAY AFTER.

(6) ASSOCIATED THUNDERSTORMS:

(a) THUNDERSTORMS ARE MORE FREQUENT OVER THE NORTHERN PERSIAN GULF.

(b) THUNDERSTORMS PRECEDE THE FRONT WHICH INITIATES SHAMAL WINDS BY 3 - 6 HOURS.

(c) THE MOST SEVERE THUNDERSTORMS OCCUR NORTH OF THE SUBTROPICAL JET AXIS.

(d) WHEN THE POLAR JET AND THE STJ OVERLAP, THEY FORM A FAVORABLE HIGH-LEVEL ENVIRONMENT FOR THE RELEASE OF INSTABILITY AND PROMOTE THE GROWTH OF CONVECTION.

(7) IF THE SURFACE WIND SPEED DURING A KAUS (SOUTHERLY WIND) IS NEAR GALE FORCE OR HIGHER, FORECAST LIGHT TO MODERATE TURBULENCE:

(a) FROM THE SURFACE TO 5000 FT OVER THE CENTRAL GULF.

(b) FROM 3000 FT TO 8000 FT OVER THE EASTERN GULF.

(8) FORECAST LIGHT TO MODERATE TURBULENCE BELOW 5000 FT BEHIND THE COLD FRONT.

(9) FORECAST MODERATE TURBULENCE IN THE VICINITY OF CUMULUS DEVELOPMENT OVER WATER BEHIND THE COLD FRONT.

(10) MODERATE MECHANICAL TURBULENCE IS LIKELY ALONG THE WESTERN EDGE OF THE ZAGROS MOUNTAINS DURING EXTENDED (3-5 DAY) SHAMALS.

(11) MOUNTAIN WAVES ARE COMMON AND ARE OFTEN DETECTABLE ON SATELLITE IMAGERY.

(12) FORECAST LIGHT TO MODERATE TURBULENCE 20000 TO 35000 FT NEAR THE POSITION OF THE STJ.

(13) WHEN THE POLAR JET AND THE STJ OVERLAP:

(a) ENLARGE THE TURBULENCE AREA TO INCLUDE THE AREA FROM THE NORTHERN EDGE OF EITHER JET TO THE SOUTHERN EDGE OF THE OTHER.

(b) FORECAST MODERATE TO SEVERE CAT FROM 15000 FT TO 30000 FT NEAR THE POLAR JET.

(c) FORECAST MODERATE TO SEVERE CAT FROM 20000 FT TO 35000 FT NEAR THE STJ.

g. Low-Level Cloud and Wind Patterns. The Shamal and Kaus are the only significant disturbances to the winter weather in this region. Winds are generally light and variable. Cloudiness is usually limited to scattered, occasionally broken stratocumulus. Middle and high cloudiness is usually associated with the passage of upper-level disturbances which might not be accompanied by low-level disturbances (i.e., Shamal, Kaus). Precipitation is limited to the more rigorous extratropical systems and is highly terrain-dependent; the Iranian coasts have much heavier rainfall than the Arabian coasts.

(1) Clouds. Mean cloudiness reaches its annual maximum during the Northeast Monsoon season but still averages less than one-third total coverage. Less than half of the total is due to low clouds. Of the low cloud total, most occurs during the passage of strong extratropical disturbances which produce a Kaus followed by a Shamal. The Kaus produces typical warm frontal weather with multilayer cloudiness and precipitation. The heaviest cloudiness occurs over the Iranian coast due to terrain effects. The Shamal usually is accompanied by a band of convective clouds. The majority of the precipitation over the Arabian shores occurs during the Shamals. As cold air sweeps out over the Persian Gulf and the Gulf of Oman, stratocumulus lines form over the relatively warm water.

By far the most common situation at this time of the year is the weak to moderate Northeast Monsoon flow regime. It is characterized by clear to scattered clouds in a rather random pattern. During this regime, diurnal effects exert a strong influence on the clouds, causing them to be oriented generally parallel to the nearby shore lines.

A feature often found in the Gulf of Oman and, occasionally, along the Makran and Arabian coasts is the "Convergence Cold Line". It is usually caused by directional convergence in the low-level flow. The convergence may be augmented by terrain channeling or by the land breeze component (or both).

(2) Winds. The pressure gradient in this region generally is such that winds tend to be northerly, but are neither strong nor persistent except during the passage of extratropical disturbances. The specific direction of the prevailing winds is dependent on the geography and topography. In the northern Persian Gulf, winds average between 10 and 15 kt from the northwest. In the southern portion of the area they are lighter and generally westerly, becoming southwesterly in the western approaches to the Strait of Hormuz. Two areas of the Persian Gulf experience stronger than average Shamal conditions - near the Qatar Peninsula and near Latan Island (off Iranian coast). This is probably due to the interaction of synoptic and mesoscale influences.

The gradient wind is usually very weak in the Gulf of Oman; surface winds are dominated by land/sea breeze effects. This results in frequent calms and considerable variability in both speed and direction. Since the land breeze is generally reinforced by the gradient wind during this period, offshore winds predominate except during the afternoon. These offshore winds tend to converge over the Gulf of Oman and result in the Convergence Cloud Lines mentioned earlier.

The strongest offshore winds (particularly in the early morning hours) are

most likely to be found off the Iranian coast. Low-level winds near the coast are strong enough (at least 15 kt) to raise dust at several places from the Strait of Hormuz to the northwest coast of India.

LOW-LEVEL CLOUD/WIND FORECAST RULES/AIDS.

A. COLD AIR ADVECTED OVER THE PERSIAN GULF AND GULF OF OMAN BY WINDS OF 20 KT OR MORE WILL RESULT IN CONVECTIVE CLOUD LINES PARALLEL TO THE WIND. SHARPNESS AND PROXIMITY OF THE LINES DIRECTLY CORRELATES WITH WIND SPEED. (THESE ARE NOT THE SAME AS CONVERGENCE CLOUD LINES CAUSED BY CONVERGING SURFACE WINDS).

B. CLOUD-FREE COASTAL REGIONS USUALLY INDICATE OFFSHORE FLOW; CLOUD LINES EXTENDING ACROSS THE COAST LINE INDICATE ONSHORE FLOW.

5.0. SPRING TRANSITION (APRIL - MAY)

5.1. General.

a. During the Spring Transition season, there is a rapid increase in incoming solar radiation as the sun moves north of the Equator. Continental high pressure zones at the surface weaken and become low pressure areas (heat lows) over the Arabian Peninsula and Indian subcontinent; upper level anticyclones form over the surface heat lows as successively higher levels are warmed. Concurrently, the northern Near-Equatorial Trough tends to follow the sun's movement northward and gradually replaces the weak low level high over the central Arabian Sea. As a result of these circulation changes, low tropospheric winds become light and variable early in the period (April). By late May, the pressure gradients have reversed from the winter pattern and wind directions typical of the summer (Southwest Monsoon) season predominate. Wind speeds are generally light except near the northeast African coast where the low-level Somali Jet starts to appear.

b. Except in the immediate vicinity of the Near-Equatorial Trough and around tropical storms, skies are generally clearer and visibilities better than during the winter. Tropical storms become the main severe weather producers during the Spring transition period — particularly as the Near-Equatorial Trough advances north of 5 Deg N. In May, a significant number of tropical systems move westnorthwest across the Arabian Sea toward the Arabian Peninsula.

5.2. Large-Scale Circulation Features.

a. During this period the upper-level Subtropical Ridge moves northward to a mean position between 12 and 15 Deg N, and strengthens. An upper-level anticyclone forms (in the mean flow) over Indo-China and drifts to a position over Tibet during the Southwest Monsoon. The resulting high tropospheric flow pattern over the Arabian Sea is weak and rather variable from day to day. Westerlies persist north of about 15 Deg N and extratropical disturbances continue to influence the Arabian Peninsula and nearby areas. Weak cross-equatorial flow toward the Southern Hemisphere provides upper-level divergence favorable for tropical cyclone development. Weak vertical wind shear favors convective activity, and other prerequisites for tropical storm development are satisfied when the northern Near-Equatorial Trough migrates to a position north of 5 Deg N. This usually occurs early in the transition period.

b. Low-level circulation changes of primary importance are caused by gradual intensification of heat lows over the continents bordering the Arabian Sea. The developing heat lows over the Arabian Peninsula and southern Asia gradually reverse the pressure gradient. The northward migration of the dual Near-Equatorial Troughs results in strengthening cross-equatorial flow toward the north near the equatorial east coast of Africa (Somali Jet). These changes result in a clockwise rotation of low-level flow in the Arabian Sea which is the precursor of the Southwest Monsoon. Mid-tropospheric subsidence usually suppresses convection (and other cloudiness) over the Arabian Sea north of the Near Equatorial Trough until late May or Early June. Skies are generally clear and visibility good during the spring transition. Except near the Near-Equatorial Trough, skies are actually clearer in the spring than in the winter. Although

sea surface temperatures increase rapidly during the period, the sea is no longer warmer than the air, thus, the low cumulus and stratocumulus common during the winter decreases.

5.3. Climatology. The following is a list of valuable references:

A. National Intelligence Survey (NIS) Part 23 for the appropriate countries.

B. AWS Technical Catalog 85/001 for the latest RUSSWOs for locations of interest.

C. USAFETAC Data Summaries for Climatic Briefs - AWS TC85/001

D. Worldwide Airfield Climatic Data

Volume II Middle East
Part I AD-A002162
Part II AD-A002163

Volume IX Africa
Part I AD-682-915

E. Worldwide Paradrop Data USSR, Asia, & Africa USAFETAC DS81/099 AD-A109-872

F. AWS Forecaster Memo - 100 series listed in AWS TC85/001

G. Solar Data 5WWP/105-3 Volumes 3 & 4

H. Lunar Data 5WWP/105-4 Volumes 3 & 4

I. Follow on Training caramates - See AWS TC85/001

5.4. Troughs and Frontal Systems.

Although weak cold fronts or troughs continue to pass over the Arabian Peninsula and the Persian Gulf during this season, they are seldom strong enough to penetrate to the Arabian coast. The weather associated with fronts/troughs during this period is of little consequence except when local squalls are spawned. These squalls can cause moderate to severe sand/dust storms which may effect coastal areas of the Persian Gulf.

In response to maximum solar insolation, the northern Near-Equatorial Trough intensifies and drifts northward with the sun's nadir. It reaches a mean position near 10 Deg N by late April and provides the conditions favorable for tropical cyclone development. Usually, migration further northward does not occur smoothly or gradually, but rather, discontinuously (i.e., the Near-Equatorial Trough in the central Arabian Sea disappears as the Monsoon Trough forms near the northern coastal areas).

5.5. Large-Scale Cloud and Wind Patterns.

a. Arabian Sea.

(1) The Spring Transition period is one of the two periods during which the meridional component of the sea-level pressure gradient reverses direction. During the northern hemisphere winter, relatively low levels of solar radiation result in the maintenance of low-level high pressure ridges over continental areas due to the cooling by long wave radiation. As the sun moves into the northern hemisphere during the Spring Transition, incoming short wave radiation exceeds heat loss by long wave radiation. The result is a very weak pressure gradient over the Arabian Sea early in the transition period which gradually strengthens as the pressure continues to fall over the land areas. The end result is a system of continental heat lows connected by a thermal trough which extends from central India across southern Asia, the Arabian Peninsula, and northern Africa.

(2) The low-level circulation at this time is generally cyclonic around the heat lows but is channeled where terrain restricts the flow, to one or two approximately opposite directions (i.e., the Red Sea). The trough of low pressure which forms over the surrounding land masses, the strengthening of the high pressure ridge over the Central Arabian Sea, and the Coriolis force reversal across the equator result in generally anticyclonic flow over the Arabian Sea. This flow is supported by the Southeast Tradewinds of the Southern Hemisphere which are channeled northward along the east coast of Africa. As this flow crosses the Equator, it is accelerated by the pressure gradient along the African Coast; eventually, this process leads to the broad, persistent wind flow of the Southwest Monsoon.

(3) As the season progresses and the effects of the solar heating over southern Asia reaches higher and higher levels, the upper-tropospheric Subtropical Ridge migrates northward and strengthens. This results in easterly flow aloft south of the axis of the Subtropical Ridge (12 to 15 Deg N). Westerlies continue in the portion of the area north of 15 Deg N but weaken rapidly in the area south of 35 Deg N (region of STJ).

(4) Weather and winds which result from these large-scale patterns are generally moderate. Early in the period, as the pressure gradient is reversing, winds become light and quite variable, particularly in the north. Cloudiness reaches a minimum due to subsidence which prevails in the area. Coastal wind patterns are largely a result of land/sea breeze effects. Generally, the only heavy weather is associated with convective activity in the Near-Equatorial Trough or with tropical cyclones.

(5) Near the end of the period, southwesterly winds along the African Coast (development of the Somali Jet) and eastern portion of the Arabian coast increase markedly. Low-level mixing causes an increase in low cloudiness which often forms in lines roughly parallel to the flow. Convective activity becomes more common over the southern Indian coast as atmospheric stability decreases. If a low-level vortex forms in this area, and moves northward along the Indian coast, the initial surge of the Southwest Monsoon (and the end of the Spring Transition Period), can be expected in 3 or 4 days.

b. Red Sea and Gulf of Aden.

(1) During the Spring Transition Period, the changes in the northern Red Sea are mainly related to cloudiness, but in the Gulf of Aden and the southern Red Sea, they are mainly related to the wind flow. Cloud coverage in the north, most of which is caused by extratropical disturbances, gradually

diminishes during the transition period as the disturbances become weaker and less likely to penetrate south of the Mediterranean. Increasing air temperatures also reduce low-level cloudiness over water areas.

(2) The wind direction reversal usually does not occur in the Gulf of Aden until late May or Early June. As the winds do become weaker, however, they are more subject to land/sea breeze effects. In the Red Sea, the Convergence Zone Cloud Band (CZCB) gradually retreats southward during the period, then disappears as the wind reversal occurs in the Gulf of Aden. Northwest flow follows the retreating CZCB. Gale force winds are rare during this season.

(c) Persian Gulf and Gulf of Oman.

(1) The effects of extratropical disturbances (i.e., cloudiness, southerly winds, etc.) generally disappear in the Persian Gulf during this season. The low-level winds, though quite light, blow more persistently from a northerly direction. Land/sea breeze effects are apparent, but the strong daytime heating causes the sea breeze to be much stronger and more persistent than the land breeze. This is particularly true along the Iranian coast.

(2) Although light winds and settled weather are the rule, squalls can occur in the western two-thirds of the Persian Gulf. These squalls are accompanied by blowing sand/dust and result from evening thunderstorms. Tropical cyclones are possible near the eastern approaches to the Gulf of Oman but are rare.

5.6. SPRING TRANSITION FORECAST RULES/AIDS.

A. THE SUNGLINT PATTERN OVER THE ARABIAN SEA PROVIDES INFORMATION ON RELATIVE WIND SPEED; A NARROW (IN EAST-WEST DIRECTION) PATTERN INDICATES WEAK SURFACE WINDS; WIDENING PATTERNS INDICATE INCREASING SURFACE WINDS.

B. THE CONTINENTAL HEAT LOWS ARE VERY SHALLOW; ANTICYCLONIC FLOW OCCURS AT 850 MB.

C. LAND BREEZES ARE VERY WEAK AND OCCASIONALLY ABSENT; SEA BREEZES ARE MORE PERSISTENT THAN DURING OTHER SEASONS.

D. IF SOUTHWESTERLY FLOW IS ESTABLISHED ALONG THE AFRICAN COAST, TROPICAL CYCLONE FORMATION AND NORTHWARD MOVEMENT ALONG THE INDIAN COAST INDICATES THE END OF THE TRANSITION PERIOD AND THE BEGINNING OF THE SOUTHWEST MONSOON.

E. COLD, HIGH PRESSURE CELLS MOVING INTO THE SOUTH INDIAN OCEAN FROM AFRICA USUALLY RESULT IN A STRENGTHENING OF THE SOUTHERLY FLOW ALONG THE AFRICAN COAST.

F. IF EXTRATROPICAL DISTURBANCES PENETRATE TO THE ARABIAN SEA LATE IN THE PERIOD, THE TRANSITION PERIOD WILL BE EXTENDED (AND THE ONSET OF THE SOUTHWEST MONSOON WILL BE DELAYED).

5.7. Tropical Cyclones. (see Fall Transition Period for more details)

a. General.

The weakening of the winds (and vertical shear) at all altitudes, the intense solar radiation, the migration of the Near-Equatorial Trough northward to the southern Indian coast, all lead to a second maximum in the monthly frequencies of tropical cyclones. The probability of a significant tropical cyclone in the Arabian Sea is not substantial for the April-May period (average of one every four years), but a threat does exist and should not be discounted.

It should be remembered that as long as the Near-Equatorial Trough remains over the sea, and the further it moves away from the equator as in Spring, the more likely it is for tropical cyclone development. The Near-Equatorial Trough doesn't move continuously northward, but changes locations and intensities from day to day. As the heat lows to the north develop the Near-Equatorial Trough tends to weaken and, finally, disappear by the summer monsoon season.

According to past records the favored area of formation for cyclones is centered near 10 Deg N and 70 Deg E. Favored tracks are generally northwestward toward the Arabian coast. About 25% of the cyclones move north roughly parallel to the India coast, then recurve and make landfall over northwestern India. In May, the majority of the cyclones cross the Arabian Sea and make landfall along the Arabian coast. April cyclones usually dissipate or recurve before reaching the Arabian coast. Only one storm in 80 years of record entered the Gulf of Oman, and none were recorded in the Gulf of Aden.

b. TROPICAL CYCLONE FORECAST RULES/AIDS DURING SPRING TRANSITION.

(1) STRONG CONVECTIVE CLOUD CLUSTERS NEAR 10 DEG N 70 DEG E SHOULD BE WATCHED CLOSELY FOR INDICATIONS OF VORTEX FORMATION.

(2) IF INITIAL MOVEMENT IS TOWARD THE NORTHWEST, FORECAST NORTHWEST MOVEMENT TO CONTINUE.

(3) IF INITIAL MOVEMENT IS NORTHWARD, FORECAST NORTHWARD MOVEMENT TO CONTINUE WITH RECURVATURE AND LANDFALL NEAR THE KATHIAWAR PENINSULA IN NORTHWEST INDIA.

(4) IN APRIL, NORTHWESTERLY MOVING CYCLONES USUALLY DISSIPATE OR RECURVE NORTHEASTWARD BEFORE REACHING THE ARABIAN COAST.

6.0. SPECIAL PHENOMENA.

6.1. DIURNAL EFFECTS.

a. Land-sea Breezes.

(1) As expected, diurnal wind changes in the tropics are most pronounced near coastlines where strong differential heating takes place. A sea breeze generally develops a few hours after sunrise, continues during the day, and then dies down after sunset. Later a land breeze develops and continues until after sunrise. The sea breeze may extend 30 to 60 nm inland, but the land breeze is of a much smaller extent. The vertical extent of the sea breeze is 1300-1400 meters (4300-4600 ft), with a maximum speed a few hundred meters above the ground due to surface friction. In contrast, the land breeze is usually only a few hundred feet deep.

(2) The sea breeze usually reaches its maximum strength in mid-afternoon and its maximum depth about 2100L, although by this time the sea breeze at the surface usually has died. Due to the surface frictional effects, the sea breeze often appears earlier and stronger above the ground level. Near the surface, the land breeze that develops after dark is usually weaker than the sea breeze. Forecasters must remember that, above the sea breeze, there is usually found an upper land breeze; above the land breeze, an upper sea breeze. These flows are generally weaker than those at the surface, with the upper land breeze usually stronger than the upper sea breeze.

(3) While the land-sea breezes are usually not significant in intensity (usually 7 m/sec or less), they may combine with the synoptic flow and must be considered when forecasting for areas near the coasts. These breezes will also effect temperature and humidity along the coastal areas. Aircraft and parachute operations may be influenced by these low-level winds.

b. Upslope-downslope Winds.

(1) Of major interest in the Arabian Sea, Red Sea, Gulfs of Aden and Oman, and to some extent the eastern Persian Gulf, are land-sea breezes when they are reinforced by upslope-downslope winds (or mountain valley winds). When mountains are located along coastlines, these winds can play an important role in the circulation pattern, especially in the absence of synoptic-scale disturbances. The upslope-downslope winds are the results of the temperature differences between the heated/cooled mountain slopes and the air at the same altitude over nearby valleys/water surfaces. During the day, the heat of the mountain slopes causes the air over these surfaces to rise; while at night, the reverse circulation with downslope winds develop due to the radiational cooling of the slopes. These circulations are normally better developed on slopes facing the sun than on shady slopes. The thickness of the upslope wind layer is generally 100-200 meters (300-600 ft) with speeds 2-4 m/sec (4-8 kt). The noctural downslope wind is usually shallower and of lower velocity.

(2) One of the best areas for the reinforcement of the land-sea breezes and the upslope-downslope winds to occur is the Red Sea/Gulf of Aden region. Along the coast of the Gulf of Aden, steep escarpments or cliff-like ridges rise abruptly a short distance inland. During the summer monsoon, generally fair skies allow a maximum of surface heat for the combined land-sea,

upslope-downslope effects to occur. The resulting gradient-level flow in the Gulf of Aden during July and August is from the west-southwest. During the morning hours (0600-0800L), downslope/land breezes prevail and cause convergence over the water; while in the afternoon (1200-1500L), upslope/sea breezes prevail and cause divergent surface winds over the water and convergence inland. These same strong diurnal wind changes can be expected in the Gulf of Oman region due to the coastal mountains.

(3) Diurnal wind changes should be expected along most of the coastal regions due to the large differential heating along the coasts under clear skies. Only during periods of cloudy weather should these diurnal wind regimes be considered of minimal importance.

c. The Mesoscale Eddy of Ras Asir (Cape Guardafui).

(1) During the summer monsoon of the western Arabian Sea, the region near Ras Asir is in the vicinity of the strong low-level jet or Somali Jet, which is discussed elsewhere in this handbook. The surface winds in this region are very strong from the south and southwest. However, within this region near Ras Asir is a mesoscale eddy which has a great influence on the surface flow.

(2) This eddy is centered between Ras Asir and Alula on the northwestern edge of the main monsoon, and is partly caused by the topography of the area. The diameter of the closed circulation appears to be only about 100 nm, but its influence appears to deform the surface flow over a much wider area out to about 250 nm. Also of interest, is an area of light mean surface winds to the northwest side of the eddy.

(3) The most important features of this eddy are:

The eddy is linked to the topography of Ras Asir. The small ridge of hills to the south of Alula has higher mean wind speeds within the southwest flow at the hills' eastern end, favoring eddy formation on the leeward side.

The eddy is evident only in the summer months and is sufficiently persistent to show in mesoscale analysis for the months of June through September.

The eddy is of mesoscale dimensions with a diameter of 100 nm at the surface, but it influences an area out to 250 nm as seen from the surface wind field.

The eddy extends upward to between 500-1000 m (1600-3300 ft) with a slope to the northeast.

6.2. METEOROLOGICAL FACTORS AFFECTING RADAR PROPAGATION

a. Persian Gulf and Gulf of Oman.

(1) During March to October, hot air flows into the Persian Gulf from Iraq and the Arabian Peninsula. A surface inversion is formed over the relatively cooler waters of the Gulf and over the top of the inversion there is a rapid decrease of moisture content with height. Intense and fairly continuous super-refraction results so that radar ranges much greater than standard are of frequent occurrence.

maximum dust frequency occurs in the Spring or Summer months for most areas of Southwest Asia. Additional activity may be experienced during the winter months in some areas associated with the winter Shamal, where strong winds resulting from the rapid pressure rises behind troughs transiting the area occur. Observations show that the highest frequencies of airborne dust occur during daylight hours, with some areas experiencing an afternoon maximum.

b. Observational data bases in Southwest Asia are very sparse and long climatological records are almost nonexistent. Recent studies of the data available suggest that the frequency of dust storms in eastern Saudi Arabia and other west Arabian (Persian) Gulf coast locations may be decreasing. There is speculation that the flooding of large areas of southern Iraq, increased construction and planting by expanding populations, increased irrigation, and other factors may be the cause for this decrease. The decrease may be due to an aberration of the limited data base, however.

c. The meteorological processes that generate dust storms in Southwest Asia can be classified as follows:

(1) Convective weather systems - thunderstorms, squall lines,

(2) Passage of frontal systems,

(3) Winds associated with permanent pressure systems, and

(4) Low-level winds associated with upper-level jet streams.

d. The World Meteorological Organization definition of a dust storm is an event that involves a reduction in visibility to below 1000 meters and a mean wind speed of 22 knots or more. This definition may not always be representative since visibilities often fall to 500 m or less with almost calm winds. In these cases, the location is often downstream of a generating area, and the resulting restriction in visibility is due to suspended dust falling out of the atmosphere rather than by dust being picked up by the winds in the local area. Visibility restrictions can be effected by the wind speed and direction, source region (topography, soil conditions, etc.), duration since the last significant rainfall, etc. Forecasters should consider these factors in determining the forecasts for visibility. There are several caramate seminars and forecaster memos to provide general guidance in dust storm forecasting.

e. From the author's own experience at Riyadh, Saudi Arabia, 25 knots was found to be about the speed necessary to product a restriction to visibility. Between 25 and 35 knots would bring rapidly decreasing visibilities down to about 2 miles and greater than 35 knots could bring the visibility down to 1 mile or less. (These observations were made during the summer months when precipitation was virtually nonexistent). There tended to be a significant reduction in visibility near sunset for about an hour when the afternoon winds decreased. Perhaps, this was due to a "settling out" of suspended particles and the effects of reduced sun angle making conditions appear worse. Before issuing a dust storm forecast, one should consider the many local factors.

f. The highest annual average of dust storm occurrence in Southwest Asia occurs in Iraq, Kuwait, and the northeast portions of Saudi Arabia. These usually occur mainly in the period March through July. There is another area with high occurrence, that is the southern portions of the Arabian Peninsula.

(2) Similar conditions persist over the Gulf of Oman from March to June, but, from July to September, the Southwest Monsoon produces the phenomena of skip distance. Although skipping at moderate ranges may not be detected, that at greater distances often is. This results from the hot, dry air from the Persian Gulf overriding the cooler, moister, denser Southwest Monsoon current and producing an elevated duct. In October, after the cessation of the monsoon in these waters, super-refraction is again fairly frequent and intense.

(3) From November to February in both Gulfs, evaporation ducts are likely to frequently occur. Ranges somewhat greater than standard occur on most occasions, although intense super-refraction is rare, so far as is known.

b. Southwest Arabian Coast.

(1) During the Northeast Monsoon (Dec-Apr) and part of the transition periods, super-refraction first becomes common at the eastern end of the coast in December and spreads rapidly southwestward, becoming general over the whole area between January and April and being most intense late in the season.

(2) During the Southwest Monsoon (June-Sep), super-refraction is not expected and ranges are normal.

(3) During the transition periods (May, Oct-Nov) super-refraction and long ranges are occasionally experienced, but conditions are usually normal.

6.3. ELECTRO-OPTICS

The atmosphere of Southwest Asia will significantly effect electromagnetic energy transmission and forecasters must consider these effects in their support to electro-optic (E-O) systems. The extreme temperatures, dust, sea salt, etc., can impact these systems. However, since much of this information is classified and probably beyond the scope of this publication, it hasn't been included. Forecasters should refer to other sources for more information on electromagnetic energy and E-O systems support.

6.4. RADIO PROPAGATION

Just as the atmosphere of Southwest Asia will effect the transmission of electromagnetic energy in the visible, infrared, laser, and other wavelengths, atmosphere attenuation of radio frequencies can also hamper operations. Forecasters should be knowledgeable of the anomalies in this region to assist their customers. Teaching of radio propagation forecasting is again beyond the scope of this publication, but forecasters may use AWS/FM-100/14 to assist them in becoming familiar with propagation climatology of the area. Forecasters should refer to AWSR 105-52 and AFGWCP 105-1 to determine what products are available to assist them in making propagation forecasts. Air Weather Service ionospheric forecasters may have to be consulted for assistance in providing specialized support.

6.5. DUST STORMS

a. Virtually all of Southwest Asia is subject to dust storm activity, since the area is largely arid or semi-arid. The highest frequency of dust storms in the region is found in the lower Mesopotamian Plains, in southern Iraq. The

maximum dust frequency occurs in the Spring or Summer months for most areas of Southwest Asia. Additional activity may be experienced during the winter months in some areas associated with the winter Shamal, where strong winds resulting from the rapid pressure rises behind troughs transiting the area occur. Observations show that the highest frequencies of airborne dust occur during daylight hours, with some areas experiencing an afternoon maximum.

b. Observational data bases in Southwest Asia are very sparse and long climatological records are almost nonexistent. Recent studies of the data available suggest that the frequency of dust storms in eastern Saudi Arabia and other west Arabian (Persian) Gulf coast locations may be decreasing. There is speculation that the flooding of large areas of southern Iraq, increased construction and planting by expanding populations, increased irrigation, and other factors may be the cause for this decrease. The decrease may be due to an aberration of the limited data base, however.

c. The meteorological processes that generate dust storms in Southwest Asia can be classified as follows:

(1) Convective weather systems - thunderstorms, squall lines,

(2) Passage of frontal systems,

(3) Winds associated with permanent pressure systems, and

(4) Low-level winds associated with upper-level jet streams.

d. The World Meteorological Organization definition of a dust storm is an event that involves a reduction in visibility to below 1000 meters and a mean wind speed of 22 knots or more. This definition may not always be representative since visibilities often fall to 500 m or less with almost calm winds. In these cases, the location is often downstream of a generating area, and the resulting restriction in visibility is due to suspended dust falling out of the atmosphere rather than by dust being picked up by the winds in the local area. Visibility restrictions can be effected by the wind speed and direction, source region (topography, soil conditions, etc.), duration since the last significant rainfall, etc. Forecasters should consider these factors in determining the forecasts for visibility. There are several caramate seminars and forecaster memos to provide general guidance in dust storm forecasting.

e. From the author's own experience at Riyadh, Saudi Arabia, 25 knots was found to be about the speed necessary to product a restriction to visibility. Between 25 and 35 knots would bring rapidly decreasing visibilities down to about 2 miles and greater than 35 knots could bring the visibility down to 1 mile or less. (These observations were made during the summer months when precipitation was virtually nonexistent). There tended to be a significant reduction in visibility near sunset for about an hour when the afternoon winds decreased. Perhaps, this was due to a "settling out" of suspended particles and the effects of reduced sun angle making conditions appear worse. Before issuing a dust storm forecast, one should consider the many local factors.

f. The highest annual average of dust storm occurrence in Southwest Asia occurs in Iraq, Kuwait, and the northeast portions of Saudi Arabia. These usually occur mainly in the period March through July. There is another area with high occurrence, that is the southern portions of the Arabian Peninsula.

These mostly occur in June, July, and August. The dust storms in Israel, Lebanon, Syria, and Jordan are less frequent and are more likely to occur in late winter and early Spring when troughs pass through the area.

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GLOSSARY OF GEOGRAPHICAL TERMS/SOUTHWEST ASIA

(G-Greek, P-Persian, T-Turkish; otherwise Arabic)

Abu	father of (tribal)	Jebel	hill
Ain	spring	Kara (T)	black
Ala (T)	very high	Kasr, Qsar	castle, barracks
Akhbar	greater	Kebir	great
Akhdar	green	Kefr	village
Asir	isolated	Khan	night stopping place for caravans
Aziab	hot,dry south wind		
Aya(Ayos) (G)	saint		
Bab	gate, strait	Khor	open water, salt steppe
Bahr	sea, lake	Maaden (T)	mine
Balkan (T)	wooden hill	Maidan (P)	open expanse, small plain
Beit	house		
Bekaa	fertile plain	Mar	saint
Bir	well	Nerj,Marj	plain
Birkeh,Birket	pool, tank	Meskin	poor
Buyuk (T)	great	Nahr	river
Col (T)	desert	Nakle	palm tree
Dagh (T)	mountains	Ova (T)	plain, basin
Dar	dwelling	Qanat (P)	canal
Deir	monastery	Ramle	sand
El(al,em,en, er,esh,et)	the	Ras	cape, headland
		Rud (P)	river
Gezira, Jezireh	island	Sabkha	salt marsh
Ghab	forest	Sahel	plain
Ghor	hollow	Sidi	tomb of holy man
Gol (T)	lake	Su (T)	river
Hamad	barren	Sur (P)	fortress
Hedjaz	boundary	Tel, Tell	small hill
Hosn,Husn	fortress	Tulul	small hills
Ibn	son of	Tuz (T)	salt
Irmak (T)	river		

Table 2

Table 3

AFGHANISTAN REPORTING STATIONS

STATION NAME	WMO #	ICAO	SYN	MET	RAW	PIB	FCST	LAT	LON
HERAT	409380	OAHR	X			X		3413N	06213E
CHAKHCHARAN	409420	OACC	X					3432N	06516E
BAMIYA	409450	OABN	X					3449N	06749E
KABUL INTL	409480	OAKB	X		X	X	X	3433N	06913E
JALALABAD	409540	OAJL	X					3426N	07028E
FARAH	409740	OAFR	X					3222N	06422E
BUST/LASKARGAN	409880		X					3133N	06422E
KANDAHAR	409900	OAKN	X		X			3130N	06551E
FAIZADAD	409040	OAFZ	X					3707N	07031E
MAZARI-SHARIF	409110	OAMS	X					3642N	06712E
KUNDUZ	409130	OAUZ	X					3640N	06855E
MAIMANA	409220	OAMN	X					3555N	06445E
NORTH SALANG	409300		X					3519N	06901E

BAHRAIN REPORTING STATIONS

STATION NAME	WMO #	ICAO	SYN	MET	RAW	PIB	FCST	LAT	LON
BAHRAI MUHARRAQ	411500	OBBI	X	X			X	2616N	05037E

DJIBOUTI REPORTING STATIONS

STATION NAME	WMO #	ICAO	SYN	MET	RAW	PIB	FCST	LAT	LON
DJIBOUTI/AMBOULI	631250	HFFF	X					1133N	04309E

EGYPT REPORTING STATIONS

STATION NAME	WMO #	ICAO	SYN	MET	RAW	PIB	FCST	LAT	LON
CAIRO INTL	623660	HECA	X	X			X	3008N	03124E
HELWAN	623780				X	X		2952N	03120E
MINYA	623870	HEMN	X			X		2805N	03044E
HURGHADA	624620	HEGN	X					2717N	03346E
KOSSEIR	624650		X					2608N	03418E
SALLOUM	623000		X			X		3132N	02511E
MERSA MATRUH	623060	HEMM	X		X	X		3120N	02713E

EGYPT REPORTING STATIONS (CONT'D)

STATION NAME	WMO #	ICAO	SYN	MET	RAW	PIB	FCST	LAT	LON
ALEXANDRIA/NOUZHA	623180	HEAX	X	X		X	X	3112N	02957E
PORT SAID	62330	HEPS	X			X		3116N	03218E
MINYA	623870	HEMN	X			X		2805N	03044E
MANKABAD/ASYUT	623930	HEAT	X					2703N	03101E
LUXOR	624050	HELX	X	X		X	X	2540N	03242E
ASSWAN	624140	HESN	X		X	X	X	2358N	03247E
SIWA	624170		X			X		2912N	02529E
BAHARIA	624200		X			X		2820N	02854E
KHARGA	624350		X			X		2527N	03032E
ISMAILIA AFB	624410		X					3036N	03217E

ETHIOPIA REPORTING STATIONS

STATION NAME	WMO #	ICAO	SYN	MET	RAW	PIB	FCST	LAT	LON
ASSAB	630430	HASB	X					1301N	04244E
DIRE DAWA INTL	634710	HADR	X				X	0936N	04152E
ASMARA/YOHANNES	630210	HAAY	X					1517N	03855E
NEGHELLI	635330	HANG	X					0518N	03942E
MASSAWA	630230	HAMS	X					1537N	03927E
GONDAR	633310	HAGN	X					1232N	03726E
BAHARDAR	633320	HABD	X					1126N	03724E
DESSIE COMBOLCHA	633330	HADC	X					1105N	03943E
DEBREMARCOS	633340	HADM	X					1019N	03745E
LEKEMTI	633400		X					0903N	03636E
JIMMA/ABA SEGUD	634020	HAJM	X					0739N	03649E
GORE	634030	HAGR	X					0809N	03533E
ADDIS ABABA/BOLE	634500	HAAB	X		X	X	X	0859N	03848E
HARAR MEDA	634510	HAHM	X					0844N	03900E
AWASH	634530	HAAW	X					0856N	04005E
AWASSA	634600	HALA	X					0704N	03830E
JIJIGA AFB	634730	HAJJ	X					0920N	04248E

ISRAEL REPORTING STATIONS

STATION NAME	WMO #	ICAO	SYN	MET	RAW	PIB	FCST	LAT	LON
ELAT	401990	LLET	X	X		X	X	2933N	03457E
OVDA	401980	LLOV	X	X			X	3000N	03450E
BEER-SHEVA	401910	LLBS	X					3114N	03447E
JERUSALEM	401840		X					3147N	03513E
TEL-AVIV BEN GU RION	401800	LLBG	X	X			X	3200N	03454E
BET DAGAN	401790				X	X		3200N	03449E
TEL-AVIV PORT	401760		X					3206N	03447E
RAMAT-DAVID AFB	401650	LLRD						3240N	03511E
HAIFA SOUTH	401550		X					3249N	03500E
MT KENNAN	401530		X					3259N	03530E

JORDAN REPORTING STATIONS

STATION NAME	WMO #	ICAO	SYN	MET	RAW	PIB	FCST	LAT	LON
AQABA INTL	403400	OJAQ	X					2938N	03501E
MA'AN	403100	OJMN	X			X		3010N	03547E
GOR EL SAFI	402960		X					3102N	03528E
QUEEN ALIA	402720	OJAI	X	X			X	3140N	03558E
AMMAN/KING ABDULLAH	402700	OJAM	X	X		X	X	3159N	03559E
MAFRAQ AFB	402650	OJMF	X		X			3222N	03616E
HOTEL FIVE	402600	OJHF	X					3212N	03708E
IRELD	402550	OJBD	X			X		3233N	03551E
HOTEL FOUR	402500	OJHR	X					3230N	03812E

KUWAIT REPORTING STATIONS

STATION NAME	WMO #	ICAO	SYN	MET	RAW	PIB	FCST	LAT	LON
KUWAIT INTL	405820	OKBK	X	X	X	X	X	2913E	04759E

LEBANON REPORTING STATIONS

STATION NAME	WMO #	ICAO	SYN	MET	RAW	PIB	FCST	LAT	LON
BEIRUT	401000	OLBA	X	X			X	3349N	03529E

OMAN REPORTING STATIONS

STATION NAME	WMO #	ICAO	SYN	MET	RAW	PIB	FCST	LAT	LON
KHASSAB	412400	OOKB	X					2611N	05614E
BURAIMI	412440	OOBR	X					2415N	05560E
SOHAR	412460	OOSH	X					2421N	05643E
SAIQ	412540	OOSQ	X					2308N	05738E
SEEB INTL AIRPORT	412560	OOMS	X	X	X		X	2335N	05817E
MINA QABOOS	412580		X					2335N	05828E
SUR	412680	OOSR	X	X				2235N	05930E
MASIRAH	412880	OOMA	X	X		X	X	2040N	05854E
RAYSUT	413120		X					1655N	05355E
THUMRAIT	413140	OOTH	X	X			X	1744N	05356E
SALALAH	413160	OOSA	X	X			X	1702N	05405E

QATAR REPORTING STATIONS

STATION NAME	WMO #	ICAO	SYN	MET	RAW	PIB	FCST	LAT	LON
DOHA PORT	411680		X					2518N	05133E
DOHA INTL AIRPORT	411700	OTBD	X	X	X		X	2515N	05134E
UMM SAID	411760		X					2454N	05133E

SAUDI ARABIA REPORTING STATIONS

STATION NAME	WMO #	ICAO	SYN	MET	RAW	PIB	FCST	LAT	LON
TURAIF/AL TURAYF	403560	OETR	X	X			X	3141N	03840E
BADANA	403570	OEBD	X					3058N	04059E
ARAR	403584	OERR		X			X	3055N	04108E
AL JOUF/SAKAKA	403610	OESK	X	X			X	2956N	04012E
RAFHA	403620	OERF	X	X			X	2938N	04329E
QUAISUMAH	403730	OEPA	X	X	X		X	2820N	04607E
TABOUK	403750	OETB	X	X	X		X	2822N	03635E
HAIL	403940	OEHL	X	X			X	2731N	04144E
EL WEJH	404000	OEWH	X	X	X		X	2614N	03626E

SAUDI ARABIA REPORTING STATIONS (CONT'D)

STATION NAME	WMO #	ICAO	SYN	MET	RAW	PIB	FCST	LAT	LON
GASSIM	404050	OEGS	X	X			X	2618N	04348E
DHAHRAN	404160	OEDR	X	X	X		X	2616N	05010E
AL HOFUF	404200	OEHF	X					2520N	04935E
MEDINA/AL MADINAH	404300	OEMA	X	X	X		X	2433N	03943E
RIYADH	404370	OERK	X	X	X		X	2456N	04643E
RIYADH INTL	404380	OERY	X	X			X	2442N	04644E
YENBO	404390	OEYN	X	X			X	2407N	03803E
SHAWALAH	410160	OESW	X					2220N	05400E
JIDDAH/ABDUL-AZIZ	410240	OEJN	X	X	X		X	2140N	03909E
JIDDAH	410260	OEJD					X	2130N	03912E
MECCA	410300	OEMK	X	X				2125N	03950E
TAIF	410360	OETF	X	X			X	2129N	04032E
AL BAHA	410550	OEBA	X	X			X	2018N	04138E
SULAYIL	410620	OESL	X	X	X		X	2028N	04540E
BISHA	410840	OEBH	X	X			X	1958N	04240E
ABHA	411120	OEBA	X	X			X	1808N	04223E
KHAMIS MUSHAIT	411140	OEKM	X	X	X		X	1818N	04248E
NEJRAN AFB	411280	OENG	X	X			X	1736N	04425E
SHARORAH	411360	OESR	X				X	1730N	04720E
GIZAN	411400	OEGN	X	X	X		X	1652N	04235E

SOMALIA REPORTING STATIONS

HARGEISA	631700	HCMH	X					0930N	04405E
BELAT UEN	632400	HCMN	X					0444N	04512E
BARDERA	632500	HCMD	X					0221N	04218E
MOGADISCIO	632600	HCMM	X	X			X	0202N	04521E

SYRIA REPORTING STATIONS

STATION NAME	WMO #	ICAO	SYN	MET	RAW	PIB	FCST	LAT	LON
DARAA	400950		X					3236N	03606E
JABAL ETTANE	400870		X					3329N	03840E
NABK	400830		X					3402N	03643E
CAMASCUS	400800	OSEI	X	X	X	X	X	3325N	03631E
ABU KAMAL	400720		X					3425N	04055E
SAFITA	400660		X					3449N	03608E
DEIR EZZOR	400450	OSDZ	X					3519N	04009E
RAQQA	400390		X					3556N	03901E
HAMA	400300		X					3508N	03645E
LATAKIA	400220	OSLK	X					3530N	03547E
HASSAKAH	400160		X					3630N	04045E
TEL ABIAD	400090		X					3642N	03857E
ALEPPO/NEIRAB	400070	OSAP	X		X	X		3611N	03713E
KAMISHLI	400010	OSKL	X					3703N	04113E

U.A.E. REPORTING STATIONS

STATION NAME	WMO #	ICAO	SYN	MET	RAW	PIB	FCST	LAT	LON
DUBAI	411940	OMBD	X	X			X	2515N	05520E
SHARJAH INTL AIRPORT	411960	OMSJ	X	X			X	2520N	05531E
ABU DHABI/BATEEN	412160	OMAD	X				X	2426N	05428E
ABU DHABI INTL ARPT	412170	OMAA	X	X	X	X	X	2426N	05439E

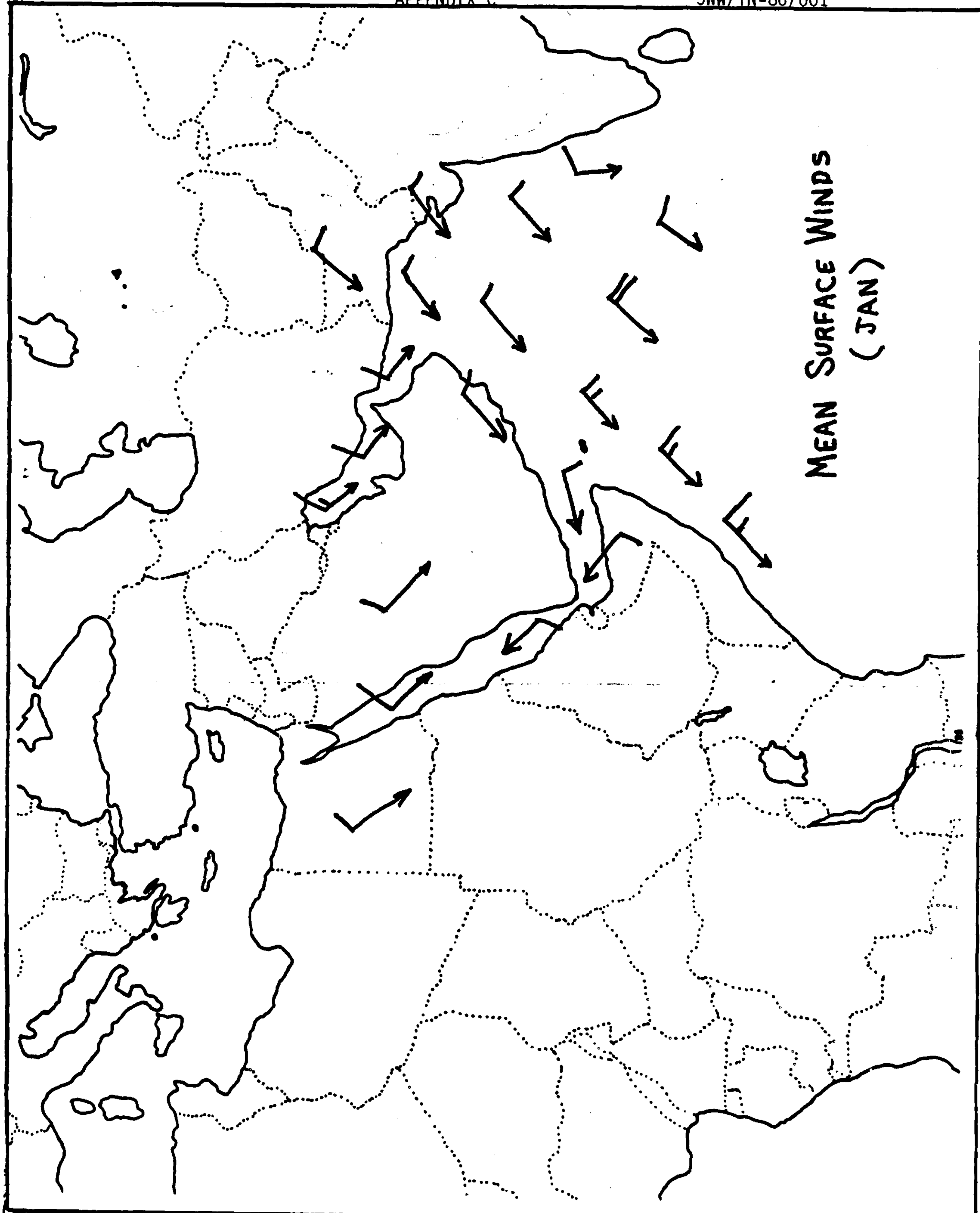


Figure 3a

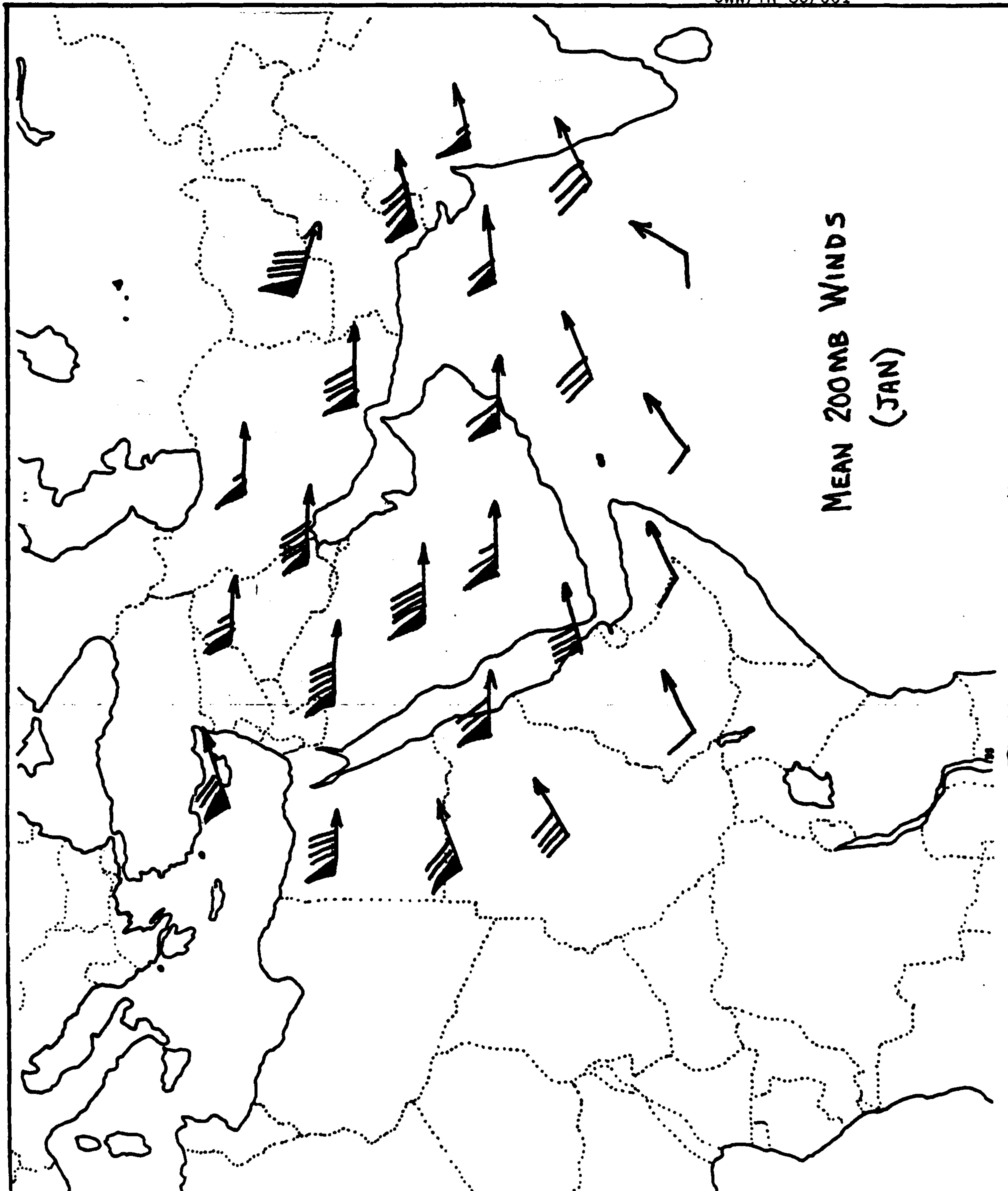


Figure 3b

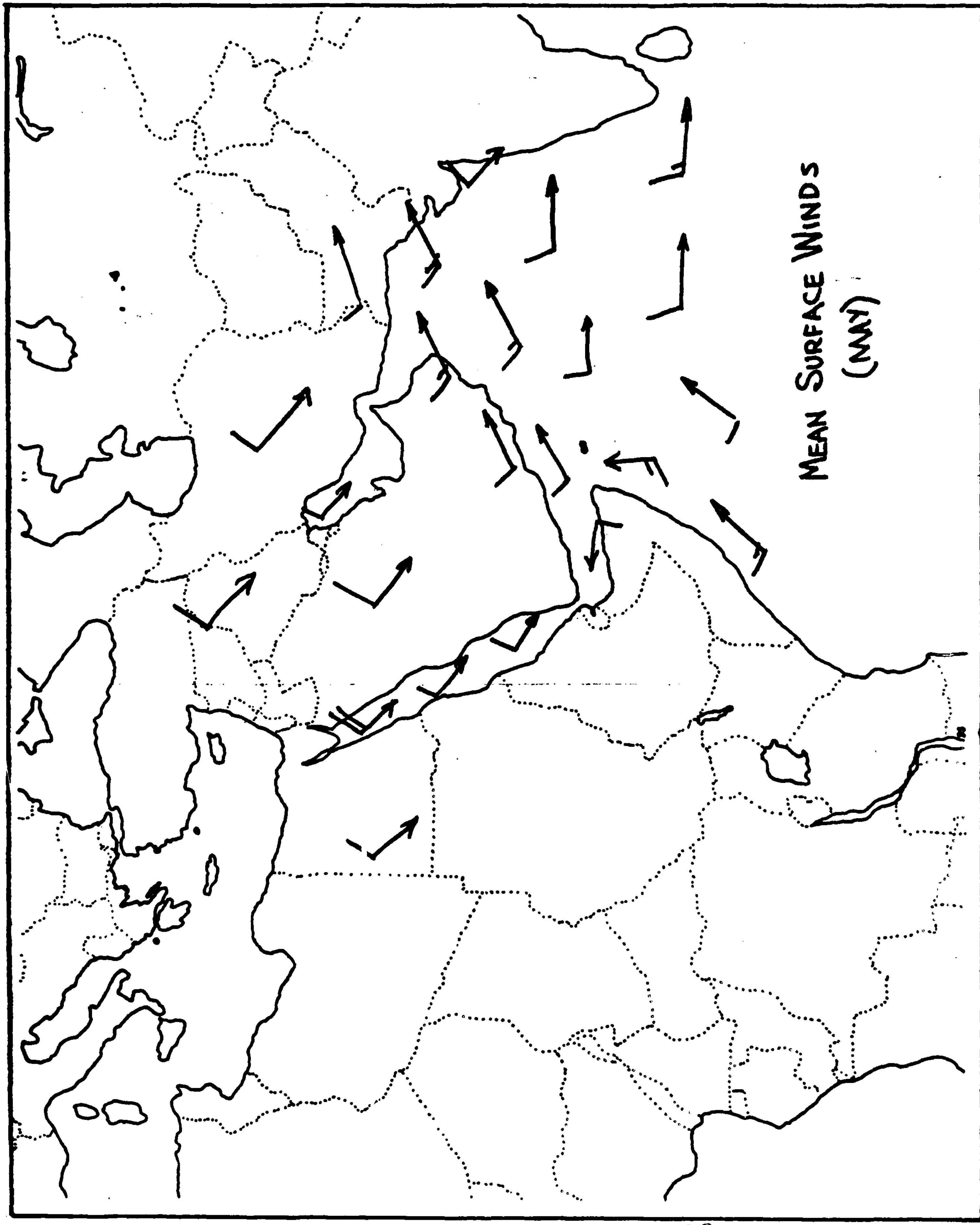


Figure 3c

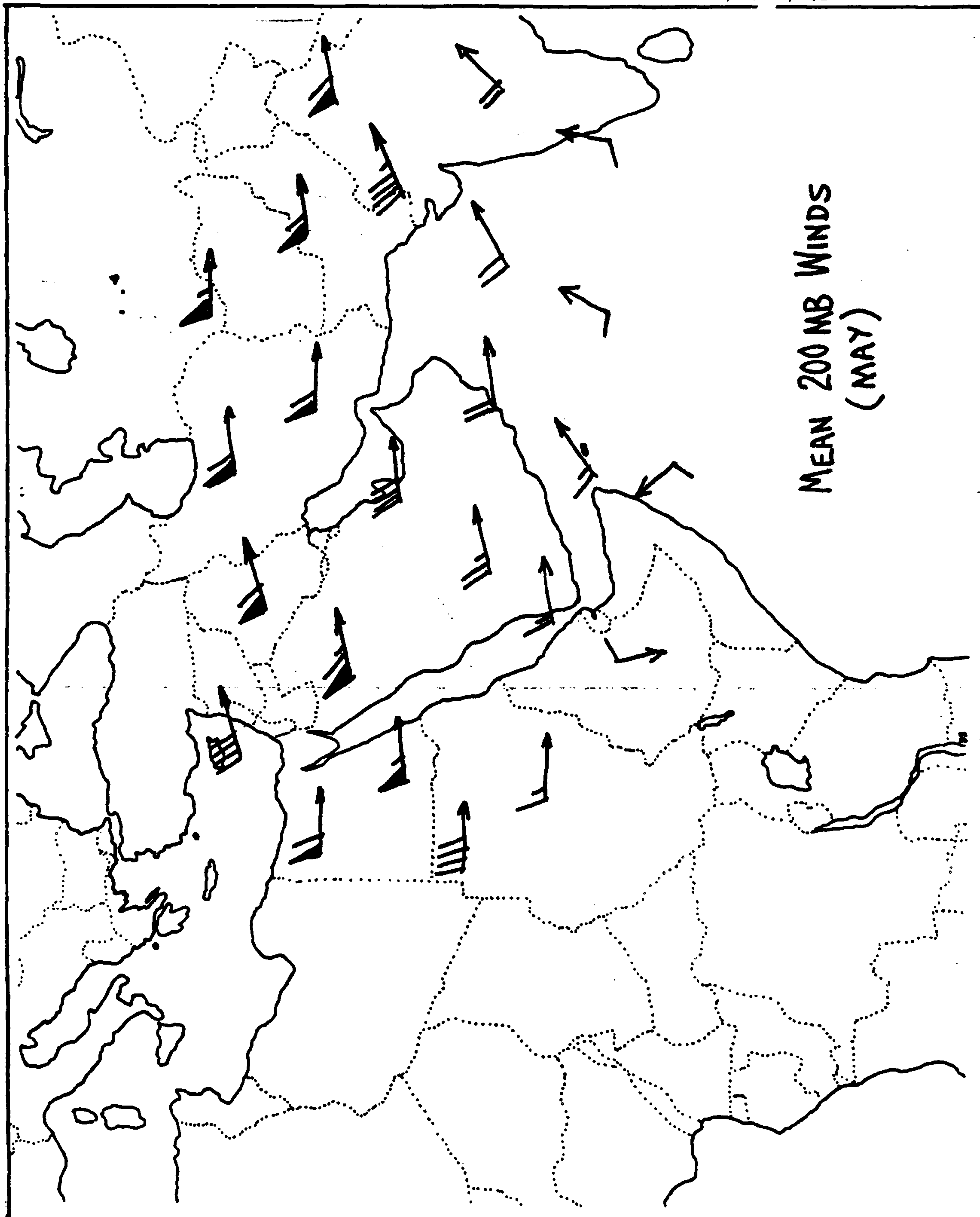


Figure 3d

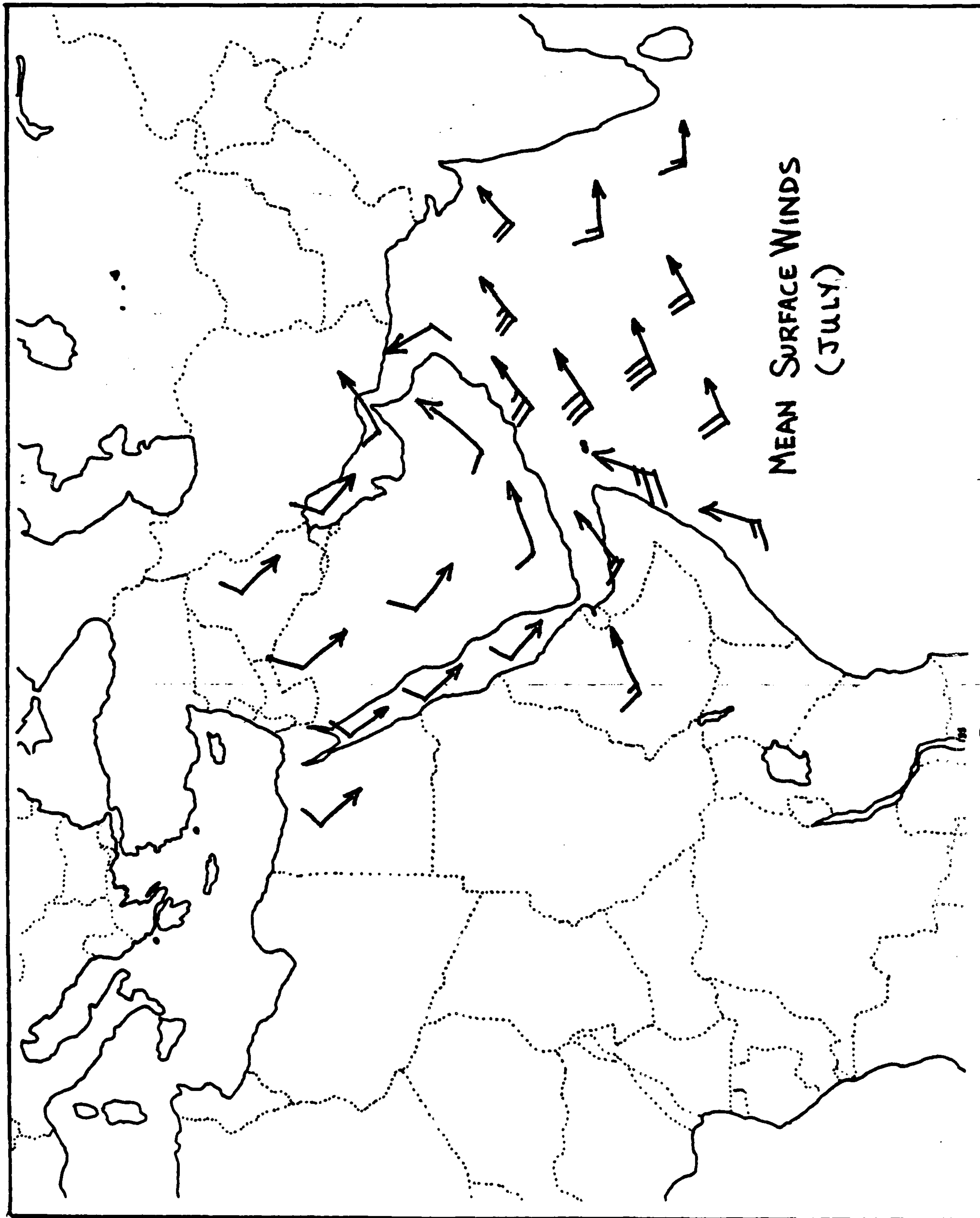


Figure 3e

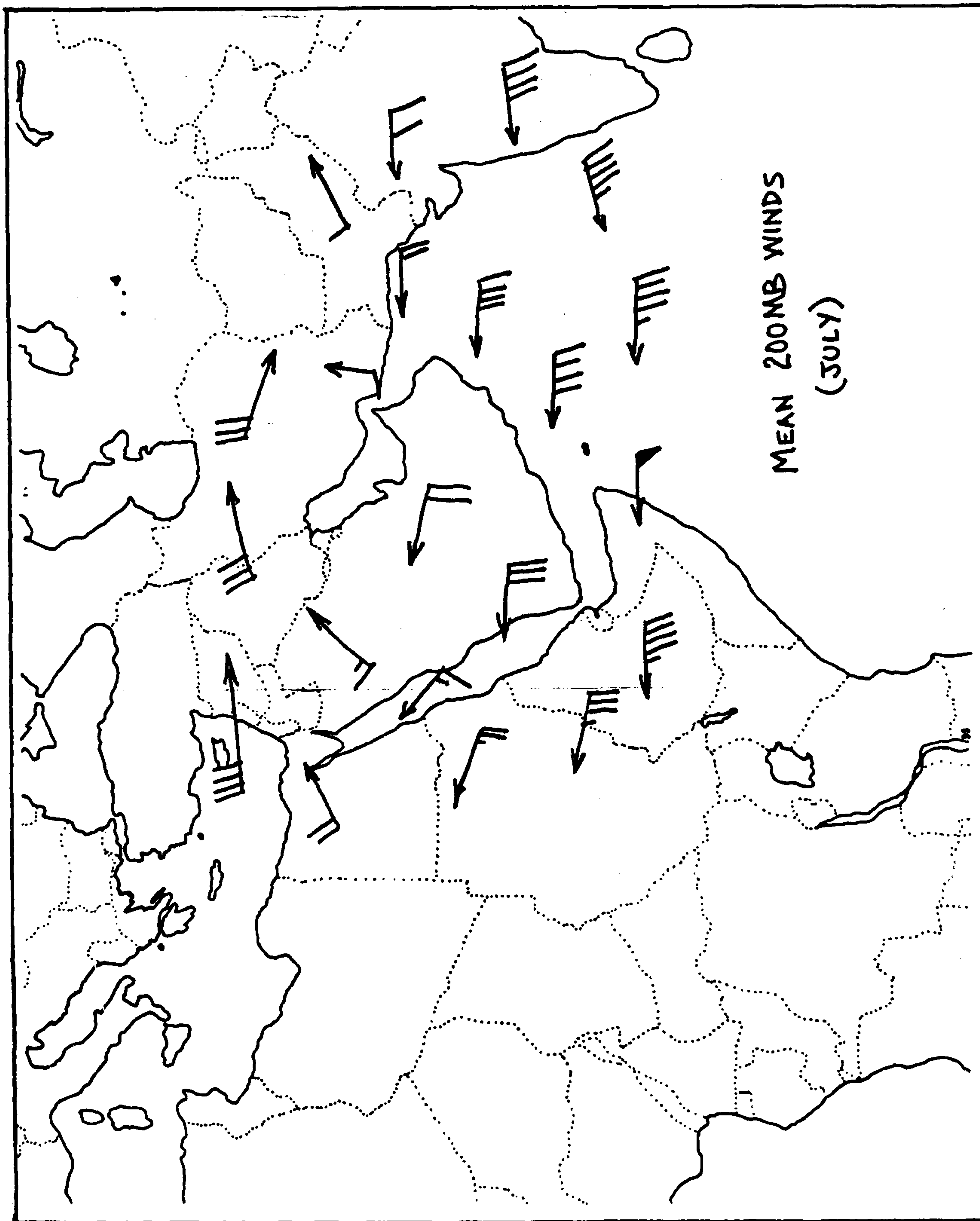


Figure 3f

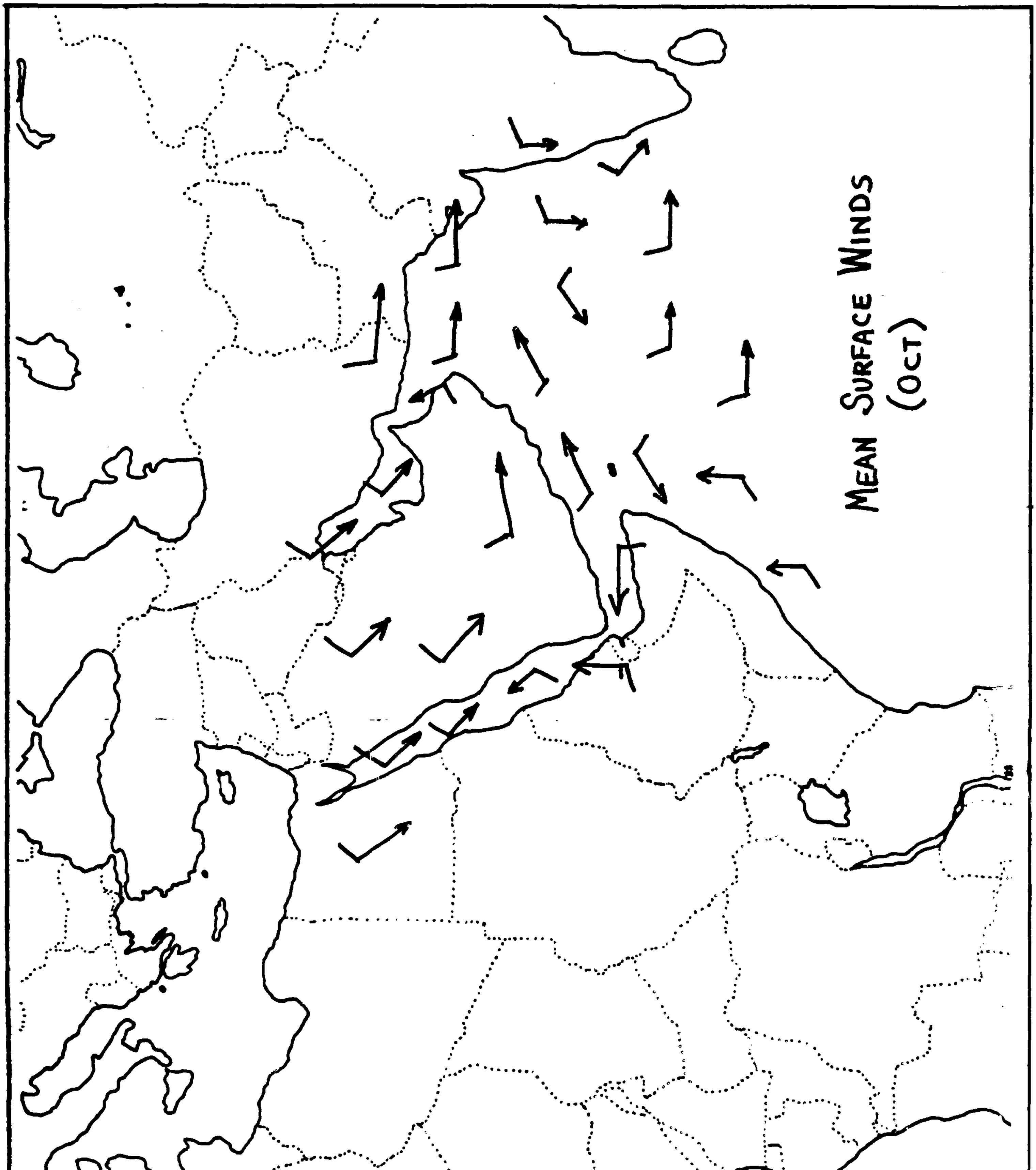
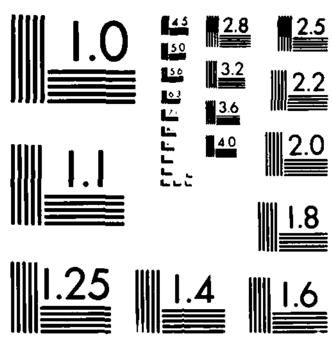


Figure 3g

AD-A175 176 SOUTHWEST ASIA FORECASTER'S HANDBOOK(U) WEATHER WING (5TH) LANGLEY AFB VA R G PEER AUG 86 5WW/TN-86/001 2/2

UNCLASSIFIED F/G 4/2 NL



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

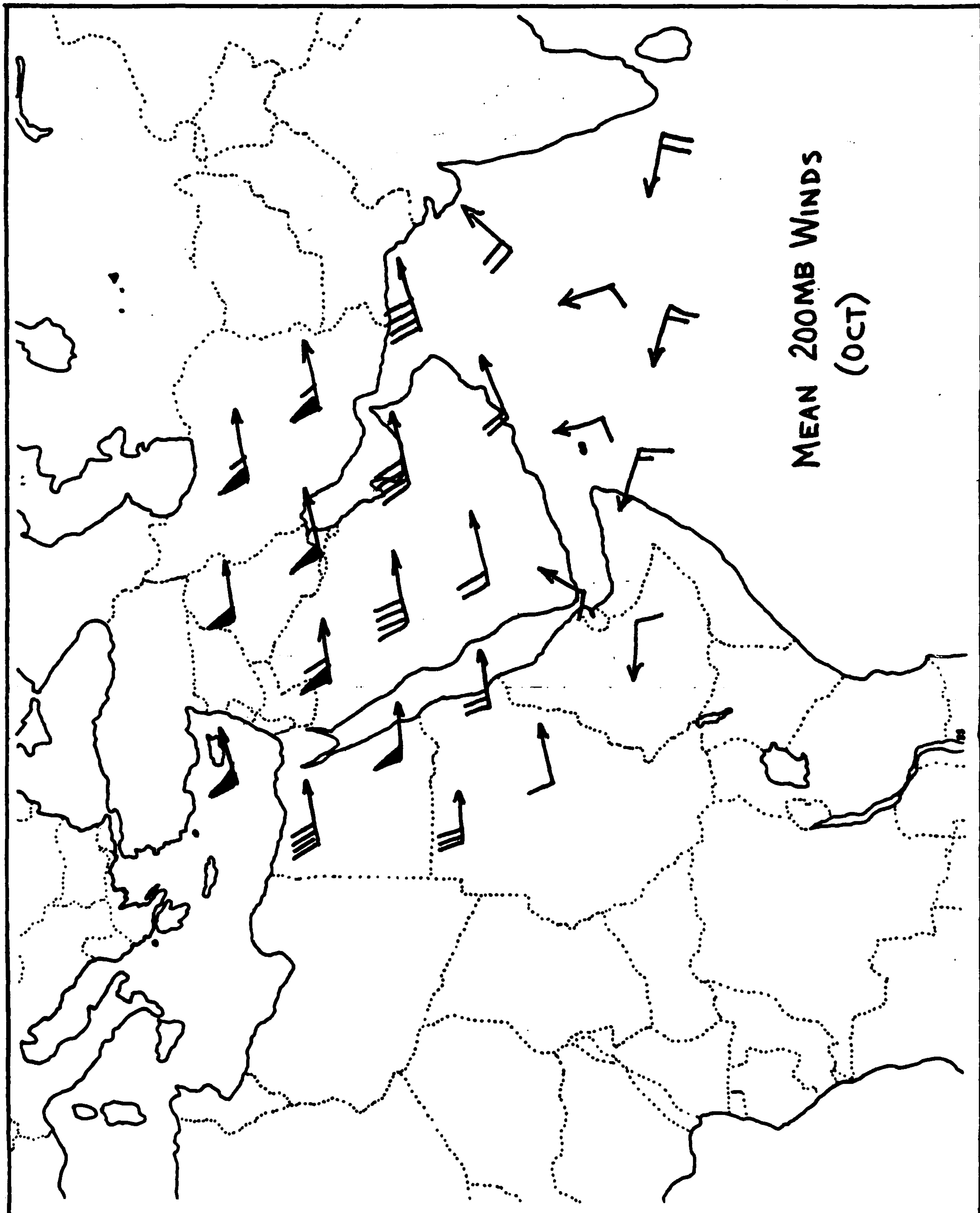


Figure 3h

END

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